THE AMERICAN ACADEMY OF ORTHOPAEDIC SURGEONS

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EDITOR

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PREFACE

Dr J E. M Thomson Lincoln, Nebraska, father of the Instructional Course Program of the American Academy of Orthopaedic Surgeons, was responsible for the first Instructional Courses, which were given at the combined meeting of the American Academy of Orthopaedic Surgeons and the Clinical Orthopaedic Society in Chicago in 1943 This program consisted of eleven major subjects presented by fifty instructors and was attended by two-thirds of the physicians registered at the meeting The immediate success of this program stimulated the founders to consider publication of the courses in a bound volume and publication of the first volume of Instructional Lectures was assured when over 500 signified that they wished to purchase a copy when available

Since that time, under the able leadership of Dr J E. M. Thomson, Dr Sam Banks, Dr Walter Blount, Dr Charles Pease, Dr Beverly Raney and Dr William Larmon, past chairmen of the Instructional Course Committee together with the unselfish devotion of those who served on the Instructional Course Committee the program has been constantly expanded so that at present it offers refresher courses on almost every subject of interest to orthopaedists. The 1959 Instructional Course Program consisted of 124 courses presented by 181 instructors and was attended by 1 700 physicians—which was again two-thirds of those registered at the meeting of the American Academy of Orthopaedic Surgeons

As in the past the subject matter of this, the sixteenth volume of Instructional Course Lectures is gathered from the various instructors who contributed to the Instructional Course Program and, as in previous years the size of the volume has been restricted in an effort to keep its price within the reach of all who wish to purchase it. It is therefore not possible to publish all of the papers which are available for publication. The Instructional Course Committee wishes to express its appreciation to all of the instructors for participating in the Instructional Course Program. The preparation and presentation of an instructional course is not an easy task and is entirely without compensation. We are especially appreciative of those who have taken the extra time and trouble to prepare their courses for publication and again we regret that all could not be included Those that have been submitted for publication but could not be included in this volume are as follows (1) Colonna, Paul C The Surgical Care of the Chronic Arthritic Hip (2) DeLorme Thomas L. Part I—Establishment of a Rehabilitation Bed Service in a General Hospital Part II—Physical Therapy in the Office Practice of Orthopaedic Surgeons (3) Goff Charles W Legg Perthes Disease (4) Herndon, Charles H. Principles of Bone Graft Surgery Different Methods of Operative Procedure and Indications for Each, Choice of Materials for Transplantation (5) Reich Rudolph The Treatment of Ununited Fractures of the Neck of the Femur (6) Thomas, George J Anesthetic Complications (7) Starr Donald E. Conservative Treatment of Cervical Spine Injuries. All credit for the success of the Instructional Course Program and for the publication of this volume belongs to the in-

structors, for without them neither would have been possible. In like manner the material contained in this volume represents the opinions of the authors and is not necessarily that of the Instructional Course Committee.

In the 1959 Instructional Course Program there were sixty nine courses repeated from previous years forty five of these have been published in previous Instructional Course Volumes and are listed on pages 7 and 8. In addition there were fifty five new courses presented, a few of which have found their way into this publication.

OTTO E. AUFRANC, M.D
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PREVIOUSLY PUBLISHED PAPERS COVERED IN COURSES AT THE 1959 MEETING

Aneff Alex J *Practical Considerations in the Electrodiagnosis of Neuromuscular Disorders* Vol. XIV page 305

Aufranc, Otto E. and Rowe Carter R. *The Shoulder* Vol. XIV page 107

Badgley Carlo E. *The Orthopedic Treatment of Arthritis* Vol. V page 314 *Primary and Secondary Congenital Deformities* Vol. X, page 143

Bateman, James E. *Peripheral Nerve Injuries* Vol XIII page 85.

Bosworth David M. *Pseudarthrosis and Method of Repair* Vol. V page 295 *Surgery of the Spine* Vol. XIV page 39

Boyes, Joseph H. *Operative Techniques of Digital Flexor Tendon Graft* Vol X, page 263

Buchman Joseph *Acute Hematogenous Osteomyelitis* Vol. IX, page 413

Campbell, Crawford J *Benign Expanding Lesions of Bone* Vol XV page 189

Colonna, Paul C. *Congenital Dislocation of the Hip in Children and Adults* Vol VIII page 169

Compere, Edward L. *Fractures of the Pelvis and Acetabulum* Vol. XI page 81

Eaton George O., and Huff H W *Medical Legal Aspects of Orthopedic Surgery* Vol. VII page 268 and Vol. VIII page 216.

Eggers, George W N *Selective Surgery for the Cerebral Palsy Patient* Vol. XII page 221

Frackelton, William H. *Plastic Surgery of Hand Injuries* Vol. XII page 131

Freeman, Smith *Skeletal Diseases Resulting From Impaired Nutrition* Vol XIV page 278.

Freiberg, Joseph A *The Diagnosis and Treatment of Common Painful Conditions of the Foot* Vol. XIV page 238.

Garceau George J *Talipes Equino-Varus* Vol. VII page 119

Gardner Ernest D *Development of Joints* Vol. IX, page 149 *Physiological Mechanisms in Movable Joints* Vol. X, page 251 *The Development and Growth of Bones and Joints* Vol XIII page 235

Ghormley Ralph K. *The Problem of Multiple Operations on the Back* Vol. XIV page 56

Goff Charles W *The Osteochrondroses With Emphasis on the Legg-Calvé Perthes Syndrome* Vol. XIII page 24

Harris, W Robert, and Salter Robert B. *Epiphyseal Injuries* Vol. XV page 206

Herndon, Charles H *Bone Graft Surgery* Vol. XV page 215

Joplin, Robert J *Some Common Foot Disorders Amenable to Surgery* Vol XV page 144

Kite J Hiram *Treatment of Congenital Clubfoot* Vol. III page 181 Vol. V page 162 Vol. VII page 117 and Vol. VIII page 181 *Congenital Metatarsus Varus* Vol. VII page 126 *The Treatment of Resistant Clubfeet* Vol. IX, page 143 *The Operative Treatment of Congenital Clubfeet* Vol. XII, page 100

McBride, Earl D *Disability Evaluation* Vol. VI page 113 Vol. XIV page 375 *The Factors Influencing Disability Evaluation* Vol X, page 407 *A Formula for Evaluating Disability* Vol. XII, page 2

Moore, John R. *Congenital Pseudo-Arthritis of the Tibia*, Vol XIV page 222.

Morris, Harry D *Amputations for Congenital Anomalies of the Lower Extremities* Vol. XV page 255.

Neviaser Julius S *Adhesive Capsulitis of the Shoulder* Vol. VI page 281

O Donoghue, Don H. *Surgical Repair of Knee Ligament Injuries* Vol. XV page 105

Pedersen, Herbert E *Lower Extremity Amputations for Gangrene* Vol. XV page 262.

Phalen, George S *The Carpal Tunnel Syndrome* Vol. XIV page 142.

Phelps, Winthrop M. *Braces—Cerebral Palsy Upper Extremity* Vol. IX, page 244

Ponseti, Ignacio V *Congenital Dislocation of the Hip in the Infant* Vol. X, page 161

Reich, Rudolph S. *Ununited Fractures of the Neck of the Femur With Special Emphasis on Treatme* Vol. VIII page 197

Riser Joseph C., Norquist Donald M., and Cockrell B Randolph *Scoliosis* Vol. XIV page 91

Sadove, Max S *Anesthetic Complications in Orthopedic Surgery* Vol XI page 279

Smith, Alan De Forest *Lumbosacral Fusion by the Hibbs Technique* Vol. IX, page 41

Steindler Arthur *The Interpretation of the Pain Syndromes in Lumbosacralgia* Vol. XIV page 11

Stelling Frank H. *Surgery of the Hand in the Child* Vol. XV page 172.

Von ackum, William H *The Surgical Treatment of Scoliosis* Vol. V page 236

Vosbell, Allen F *Anatomy of the Knee Joint* Vol. XIII page 247

White, Harvey *Hip Diseases in Children—the Roentgenographic Findings* Vol. XV page 283

Williams, Paul C. *The Conservative Management of Lesions of the Lumbosacral Spine* Vol. X, page *The Diagnosis and Conservative Management of Lesions of the Lumbosacral Spine* Vol. IV pa 103

CONTENTS

PART ONE / SYMPOSIUM ON INJURIES TO ATHLETES — 11

OPENING REMARKS (D. H. O'Donoghue, M.D.) — 13

PREVENTION OF ATHLETIC INJURIES (Donald B. Slocum, M.D.) — 17

INJURIES TO THE KNEE (B. [illegible], M.D.) — [illegible]

DIAGNOSIS AND TREATMENT OF ANKLE INJURIES SUSTAINED IN SPORTS ([illegible]) — [illegible]

REHABILITATION IN ATHLETES (Marcus J. Stewart, M.D.) — [illegible]

CLOSING COMMENTS (D. H. O'Donoghue, M.D.) — 49

PART TWO / THE HAND — 51

ANATOMY OF THE HAND ([illegible] H. Stein, Jr., M.D.) — 53

DUPUYTREN'S CONTRACTURE—FASCIOCENTESIS AND SURGICAL MANAGEMENT—A NEW CONCEPT (J. Vernon Luck, M.D.) — 70

SURGERY OF THE PARALYTIC HAND (Daniel C. Riordan, M.D.) — 79

PART THREE / THE FOOT — 91

TREATMENT OF CLUBFOOT (J. [illegible] C. McCauley, Jr., M.D.) — 93

THE SURGICAL RELEASE OF FIBROUS TISSUE STRUCTURES RESISTING CORRECTION OF CONGENITAL CLUBFOOT AND METATARSUS VARUS (Clarence H. Heyman, M.D.) — 100

THE DIAGNOSIS AND TREATMENT OF CONGENITAL CONVEX PES VALGUS OR VERTICAL TALUS (Clarence H. Heyman, M.D.) — 117

THE ROLE OF SUBTALAR FUSION IN THE TREATMENT OF VALGUS DEFORMITIES OF THE FEET (David S. Grice, M.D.) — 127

PART FOUR / THE KNEE — [illegible]

INJURIES AND AFFECTIONS OF THE MENISCI OF THE KNEE (Emanuel B. Kaplan, M.D.) — 143

	INTERNAL DERANGEMENTS OF THE KNEE *(Keene O Haldeman M.D)*	161
PART FIVE	THE SPINE	171
	DIAGNOSIS TREATMENT AND REHABILITATION OF THE INDUSTRIAL LOW BACK CRIPPLE *(Chester C Schneider M.D)*	173
	FUNDAMENTAL PRINCIPLES AND TREATMENT OF SCOLIOSIS *(Albert C Schmidt M.D)*	184
	END RESULTS OF REMOVAL OF PROTRUDED LUMBAR INTERVERTEBRAL DISCS WITH AND WITHOUT FUSION *(H Herman Young M.D and J Grafton Love M.D)*	213
PART SIX	UNEQUAL EXTREMITIES OSTEOMYELITIS ELECTROMYOGRAPHY IN ORTHOPAEDIC SURGERY	217
	SURGICAL CARE OF UNEQUAL EXTREMITIES *(Charles Weer Goff M.D)*	219
	OSTEOMYELITIS (Joseph Buchman M.D)	232
	ELECTROMYOGRAPHY—ITS APPLICATION IN ORTHOPAEDIC SURGERY *(J R. Close M.D)*	246
PART SEVEN	FRACTURES	263
	OPERATIVE TREATMENT OF FRACTURES OF THE ELBOW IN ADULTS *(Leonard F Bush M.D and Edward J McClain Jr., M.D)*	265
	SYMPOSIUM ON TREATMENT OF FRESH FRACTURES OF THE FEMORAL NECK WITH A PROSTHESIS	278
	A HISTORICAL PERSPECTIVE OF THE EVOLUTION LEADING TO PRESENT CONCEPT OF TREATMENT *(James E M Thomson M.D)*	278
	STATISTICAL REVIEW *(Claude N Lambert M.D)*	280
	PRIMARY PROSTHETIC REPLACEMENT IN FRACTURES OF THE FEMORAL NECK *(C F Ferciot M.D)*	283
	USE OF A PROSTHESIS IN THE FRESH INTRACAPSULAR FRACTURE OF THE HIP *(Palmer Eicher M.D)*	287
	FRESH FRACTURE OF THE HIP TREATED WITH *PROSTHESIS (Mark B Coventry M.D)*	292
	PROSTHESIS INDICATIONS IN FRESH FRACTURES AND BASIC *CONSIDERATIONS* AFFECTING CHOICE OF A PROSTHESIS *(Frederick R Thompson M.D)*	299
	THE MOORE SELF LOCKING VITALLIUM PROSTHESIS IN FRESH FEMORAL NECK FRACTURES *(Austin T Moore M.D)*	309
	SUMMARY *(James E. M Thomson M.D)*	322

PART ONE

SYMPOSIUM ON INJURIES TO ATHLETES

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OPENING REMARKS

It has true significance that we are having a separate symposium on the subject of injuries to athletes. Ten years ago this would not have been likely. There has been a tremendous upsurge of interest in this subject, not only among orthopaedists but also among physicians in general, and indeed among the laity. In the past few years there have been an increasing number of medical sessions devoted to this subject. I had the privilege of participating in a postgraduate course on this subject sponsored by the University of Colorado at Denver less than three years ago in which they had expected from thirty to forty registrants and were amazed to have almost three hundred very interested and enthusiastic physicians, orthopaedists, coaches, and trainers. The following year the attendance was markedly increased over that number. Within this single year there have been many sessions held throughout the country in which the various members of this panel have participated, along with many other physicians and other interested authorities.

Organized athletics have been extended to involve a major and more inclusive segment of our youth. In many areas not only the junior high but also the grade schools participate in competitive sports. There is no present trend toward less athletics. On the contrary, the trend is toward a more inclusive program. Indeed, one of the major criticisms levied at athletic programs has been their tendency to include the few to the neglect of the many. It should be recalled that in this country the various types of organized athletics, many of them competitive athletics, must serve the whole function of physical education, whereas in other countries there are various health clubs, hiking clubs, ski societies, etc. This latter type organization has not been popular in the United States. Our citizens are a keenly competitive group and exercise for exercise' sake, the calisthenic drill, the regimentation into marching clubs has not been popular here—one reason being, I believe, the fact that these various groups have been used as springboards for political activity in other countries. Our youth have an almost paranoid dislike of anything which smacks of regimentation. The effort, therefore, must be not to decry athletics and demand less participation but, on the contrary, to demand greater participation and then see to it that the whole background of organized athletics is improved.

There can be no denying that competitive athletics have a great appeal to the mass of our people. However, the major interest has been directed away from those factors which make athletics most important. The public is more inclined to look at the score, to observe the outstanding player, and to foster the competitive contest, rather than to direct its attention toward those facets of the program which are best calculated to return the major good to the greatest number. Comparatively little attention has been paid to either the conditioning of the athlete or the prevention of his injury. An occasional outburst of indignation may follow the untimely death of a budding prep school player. The sports page eagerly plays up injury to the star. Wryly enough, the reporter moans that the star has been disabled by his operation rather than by his injury. Some personal experience by the writer will often trigger a

lay magazine article on the importance of proper equipment and on the value of physical conditioning as factors in the prevention of injury. In the final analysis, however, the lay public and I fear the majority of our medical profession have little knowledge of the actual processes of training and little knowledge of the actual mechanics of injury. One may presume that a group such as this audience does have major interest and indeed does have information about both of these subjects. However, I am sure that each of us has much to learn from our colleagues in the training room, in regard to conditioning and equipment.

How about all this emphasis on athletics—particularly competitive athletics? Why is it important for young men to participate in athletics? Certainly there are many quaking parents who feel at times that the solution to the problem of athletic injury is to abolish athletics. Certainly abandonment of sports would be the quickest way to prevent injury to the contestant. Therefore, it is up to us to be able to demonstrate true, tangible values from athletic competition in order to justify participation in an activity which does carry an element of risk. Are *there true, tangible benefits to be derived from* athletics?

I do not think it is necessary to take up too much time with discussion of the benefits of athletics. Certainly some of them are obvious. No one seriously doubts that the athlete does develop a stronger more healthy body. Most of the myths of catastrophic sequelae from strenuous athletic activity have been dispelled. Also, I think most of us would agree that competitive athletics do have a salutary effect upon the character of the participant. This is particularly true if the programs are so managed that overmuch emphasis is not placed on winning but that more emphasis is placed on the vital ability of the athlete to value his own and respect his opponents capabilities. The player learns the value of team participation, that he must sacrifice immediate gain to the final end, and that desire is one of the most important factors in success. Also there are *certainly material benefits in our present educational* system which have much importance. Many a young man is able to go to school because of his athletic ability. Who are we to say that the athletic scholarship is not as worth while as the scholarship for merit in other fields? In most of the better schools of the country the scholarship athlete maintains a scholastic average higher than the average of his school. A good estimate of the quality of the scholarship program in a given institution can be made from the proportion of the scholarship boys who go ahead to graduation.

So much for the benefit of athletics for the student in school. What about after graduation? There is a continually greater tendency for the athlete to stay in some related field after his graduation. The conditioning of our youth depends upon the organized type of athletic training which he gets in the elementary and secondary schools and such organizations as the YMCA and Boy Scouts. Without the trained athlete these programs would be in a sorry state indeed, so far as being able to provide capable leaders is concerned. We need these people. Indeed, we will find that much of the physical education of our youth is in the hands of the former athlete. Certainly there are real advantages to an athletic program, from many standpoints.

Why then is there such bitter opposition to organized competitive athletics as such? Not because of any scholastic interference, not because of any moral implications, not because the aftereffects of training impair the physique in later life but it is because of one principal thing, namely, physical injuries.

Do athletes get physical injuries? The answer is "Yes, they do." Here is a very real objection to the athletic program—in fact, almost the only real objection. Our youngsters do get injured. Our youngsters do on occasion get seriously injured. They even get fatally injured. It must then be the duty of the medical profession to accept this challenge and do everything in its power to minimize the things which interfere with the goals of the athletic program. What can we as orthopaedists do to prevent injury, to minimize temporary disability and to prevent permanent disability?

Much indeed has been accomplished in the past few years toward these ends. A few years ago the trainer in the average scholastic institution was a fugitive from the supply room, having graduated into the "wrapping and taping" club largely by osmosis. He had no real knowledge of injuries and his main concern actually was to keep the player playing willy-nilly. We all remember the famous men who attained a great deal of notoriety by certain abilities to keep the athlete in the game. Too many times this goal of immediate playing was a more vital one than the final goal of complete recovery of the patient. During that era the doctor was a

"necessary evil." The player felt that once he reached the doctor his days as an athlete were over. In too many instances this feeling was justified for two very pertinent reasons. First, since the doctor was the last resort, he did not see the player at the time he could really have done the most good. Second and I think of almost equal importance, was the fact that to the doctor the point that the player was an athlete or was able to remain one was not of any immediate concern. All too many times the first recommendation the doctor made was "Well, give up football" or "You must not play any more baseball." This simply tended to confirm the conviction of the player, the coach, and the public that athletes and physicians were incompatible.

However, in our major institutions this is no longer true. In the well-run athletic program of today, the coach, trainer, team physician, and specialist *all* combine in one effective unit designed to make the player well equipped and in ideal condition. In fact, more emphasis is placed and actually more time is spent on preparing a player to participate and on preventing his injury than is spent on treatment. The time when the player, coach, trainer and physician were all working at cross purposes is rapidly becoming a thing of the past in our better institutions. Athletic injuries are much less frequent than in the past. Injuries are less severe. The period of disability is shorter. The degree of recovery is more complete. Many factors have combined to cause this vast improvement in the one area where it must be conceded that athletics may have a bad effect.

So we find that once again the orthopaedist must become not only the doer but also the teacher. He must prepare himself to handle injuries to athletes and he must in turn pass this information on to the team physician, who is in the final analysis a major component in the management of the athlete. It must be recognized that there is one overriding difference in the management of injuries to athletes: the patient must get complete recovery from his injury or he is no longer an athlete. True enough, this *should* apply to *any* injury the doctor sees, but nowhere else is it dramatized quite so constantly as in the care of the athlete. So while we will discuss today some facets of prevention of injury, the major emphasis will be placed on treatment.

The single outstanding and most important consideration in the treatment of athletic injury is early detection, not only of the nature of the injury but also of its degree. The optimum time to examine an athlete for injury is as soon as possible after he is hurt. There must be no compromise with this statement. It may be impossible to examine the patient at this time. It may be impossible to make a complete diagnosis at this time, but if it is possible, precious time has been saved. Frequently the initial examination is by the coach or by the trainer or by the physician on the field. Whoever this is, he must make as careful an evaluation of this player's condition as he is capable of making and must pass this information on to each succeeding link in the chain of therapy. The doctor must conscientiously and objectively examine the player. Does the injury seem serious enough that the boy should not return to the game or should he be strapped up and allowed to return? To err is human, but the margin of error can be drastically reduced by comprehensive consideration of the patient's injury. There is no place here for wishful thinking. The player is eager to continue and should not be deprived unnecessarily of this privilege. On the other hand, if continued competition adds to the hazard of injury, he should not be permitted to compete. It is, of course, always better to err on the side of conservatism.

After the injury sidelines the player, what then? The prevalent habit of packing the injured part in ice and delaying examination until a convenient time within the next day or so is to be deplored. Your examination as a physician should be made at the earliest possible moment—even at considerable inconvenience to yourself, to the coach, or to the player. It should be obvious that the part should be undressed, all taping or strapping removed, and a real examination made. Frequently the diagnosis, which will be easy if done early, becomes exceedingly difficult later as pain increases apprehension and as swelling, edema, and hemorrhage interfere with an accurate evaluation of the injury.

Once treatment is decided upon, the physician should proceed to carry it out with confidence. You as the orthopaedist should have enough integrity to be able to cooperate with the referring physician and "take the monkey off his back," as it were, in regard to the severity of the injury. This is particularly true in regard to the decision as to whether he should be allowed to compete, whether it be permanently or temporarily. If the injury is something that the team physician should treat, he should be permitted to do so. If the specialist's attention is required, the specialist himself should not hesitate to say so. The physician

should be encouraged to seek the specialist's advice early and this can be done only if rapport with the orthopaedist is such that there is fullest cooperation between the player, the referring physician and the specialist.

I have found the following concepts of treatment to be of great value

1 The goal must be 100 per cent recovery While this may not always be possible in any given case, it must be the goal. The athlete is basically in good condition and can well tolerate any reasonable measure if it serves to increase his chances for a complete recovery

2 Adopt the *best* method of treatment. Medical evaluation of the nature and extent of injury must be the controlling factor in any decision concerning treatment. A temporizing attitude will not accomplish the best results. If you really believe that one method is distinctly better than another you should recommend this and carry it out. This must be an entirely objective decision. How often do we hear the statement "Well, perhaps this knee would be better if operated upon, but I'll put it in a cast" or "We really should have put the boy on crutches, but "

3 Avoid expediency Outside influence must not be permitted to outweigh sound medical judgment. Many pressing factors will tend to influence the doctor's decision. All concerned are extremely unwilling to believe that the player is really hurt, yet the boy's desire to compete, his fear of failing his teammates, the parents' desire to see their son excel, and the coach's hope that the player is not really hurt must all be ignored if the proper conclusion is to be reached. Procrastination, vacillation, so-called conservative attitudes must not prevail. Temporary convenience must be abandoned for the ultimate goal.

4 The treatment must be prompt. A definitive decision as to the proper method of treatment must be made at the earliest possible moment and then carried out.

5 Last and not least, the physician—not the player not the coach, not the parents, but the physician—must recognize the value of competitive athletics. He must believe that to this particular patient it is vital that he be restored to competitive athletics. If he fails in this, the patient-doctor relationship and confidence becomes lost. The doctor who deprecates the player's ambition should not be treating him.

Will such a program be accepted? Yes, but not without some time and effort on the part of the doctor He must be able to show conclusively that the program is better not for the doctor but for the school, for the coach, and especially for the player This may require some educational effort. It *will* require time. The doctor himself must be prepared to cooperate fully with interest and ability As the doctor's program is improved, those most concerned will note the results. They will observe that the sprained ankle responds to treatment, that a short, complete lay off is followed by normal ability as opposed to an ineffectual season. The coach will observe that prompt treatment restores the player more rapidly permits more actual playing in the long run, and so is better for all. The player will not fear the doctor who has a sympathetic and understanding attitude. He notes that his buddy gets well. He also expects to get well and will accept the physician's recommendation for treatment. He may fear some specific part of the treatment, such as the insertion of a needle into a joint, but not to the extent of failing to return or of refusing the treatment, provided he believes that you believe in restoring him to his normal ability

Now let us proceed to the more interesting and vital part of this general discussion, namely the management of specific conditions, with particular reference to the treatment of athletes.

DONALD B SLOCUM M D
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REVENTION OF ATHLETIC INJURIES

It is the fundamental concept of this paper that majority of sports injuries are preventable. As h it is the purpose here to outline those factors ich have been of proved value in minimizing letic trauma and to present others which suggest ure fields for investigation. The orthopaedic geon by the very nature of his calling looks the problem from the viewpoint of the bio-chanical safety engineer To analyze the situa n adequately requires knowledge of the individual man machine the nature of the forces to which is subjected the conditions of play and the human riables which may alter the best laid of safety plans. broad is the scope of athletic endeavor and so fferent the requirements for its participants that it ould be presumptuous to assume that they could be vered here in their entirety Rather a general basis r evaluation of injury-producing factors will be pre nted to aid in the analysis of a given situation ther than to cover the problem in ultimate detail.

For those of us some years away from vigorous hletics there is a tendency to forget the ruggedness body contact sports, the wide ranges of joint mo-on required in their performance, the extent of the uscular effort involved and the safety measures ken to avoid injury by means of protective equip-ent training and conditioning and knowledge of me skills. For instance in observing runners one impressed by the multiplicity of motions in the wer extremity from the time the foot strikes the round until take-off At the initial phase of weight earing the foot may strike the ground either on the e and ball of the foot flat footed, or on the heel followed by the toe. The muscles of the leg receive the impact of weight bearing from a position of 10 to 30 degrees of knee flexion. The quadriceps are fully active to receive the body load. The pelvis is rotated forward and associated lumbar lordosis remains suf ficient only to accommodate the hip extension of the trailing leg (The degree of lordosis will depend on length of stride and is greater in sprints and less in the early and mid portions of a distance race.) As the leg passes through mid stance to initial take-off the foot is seen to go into dorsiflexion of 20 to 30 de-grees, the calf muscles contract synchronously with the quadriceps to effect coordinated extension of the lower extremity and the gluteus contracts strongly to pull the leg beneath the body and throw the body into a phase of glide in which there is no weight bearing by either foot. During this phase the foot goes into full equinus followed by dorsiflexion above a right angle the knee gradually goes into full flexion to a point where the calf rests against the thigh and the hip passes from full extension into flexion of 60 degrees or more Throughout this entire cycle the excellent runner will maintain an erect body posture to mini mize the effort of the postural muscles. The shoulders move backward and forward in a manner reciprocal with the lower extremities. In observing such a runner one is constantly impressed by the wide range of motion required by the joints, the total muscular development and the training and conditioning to a point where movements are coordinated and auto-matic. In football, basketball, and other sports re-quiring a lateral movement one is once again impressed by the excellent body posture with forward

rotation of the pelvis to permit wide external rotation of the hip. In pivot" requiring external rotation of the hip the pelvis is rotated forward and the back is flat in pivot requiring internal rotation of the hip the pelvis is rotated backward with accompanying mild lumbar lordosis. Throughout sports the protective mechanisms of the body are evident for example, there is coordinated flexion of the hip knee, and ankle during the jarring initial phase of weight bearing and similarity there is springlike shock absorbing flexion of the upper spine under impact loads either from the shoulder or head above or from jarring impact with the ground below It is to be noted that the more erect the dorsal spine is, the more easily it will receive such trauma because of the wider range of flexion possible before weight falls heavily on the vertebral bodies and the intervertebral discs.

Lowman has pointed out that "a machine with properly aligned working members acts efficiently and, with care, lasts much longer than one which is out of line. In the malaligned machine the wear and tear on bearings increases the stress and strain on the working members and produces general structural depreciation [in the human machine] the maintenance of alignment is effected by the balance of all muscles activating or acting on any joint and the forces applied must be equated with age and structure of all the parts of the human machine and adjustments made in accordance with physiological age, musculoskeletal integrity and neuromuscular control."* Body alignment depends not only upon the integrity of the joints themselves but also upon the muscles acting upon the joints.

PRE-PARTICIPATION PHYSICAL EXAMINATION

The first step in athletic safety is to ensure the physical fitness of the participant through a pre participation physical examination. This serves three distinct functions (1) It determines which athlete is physically qualified to participate in a given sport and eliminates the unfit. (2) It qualifies him as to the type of sport in which he may safely participate. (3) Treatment can be instituted to bring him to a physical level which will permit participation in a given sport and/or improve performance While admittedly such examinations are best carried out on an individual basis, practical necessity due to limitations imposed by time, lack of qualified personnel economics, and individual and parental cooperation has frequently led to the practice of mass examination. Necessarily this is designed as a screening procedure to eliminate the obviously unfit and segregate those with questionable defects for further definitive medical studies. It is here that the orthopaedist enters the picture.

Physical examination is most important in the pre adolescent period and becomes progressively less important throughout high school and college years, since the repeated examinations to which these groups are subjected eliminate the majority of the unfit. It is probably well to state here that the objective of such examination is not only to determine which players meet all physical qualifications and thus may participate with safety but also to determine whether an individual may play safely in spite of definite, recognized defects which appear detrimental on screening examination but, on thorough study can be classified as nonharmful. Thus an individual with an old, asymptomatic nonunion of the carpal navicular bone might perfectly well participate in football and track but his condition might be definitely aggravated if he were to enter a sport such as basketball where rapid, repetitive motions of the wrist are required. Similarly a patient with a minor skeletal defect might safely participate in the sport of his choice after a thorough evaluation. Examinations successively through the growing years are worth while. For example, the tall, spindly youth with relaxed ligaments might necessarily be eliminated from contact sports at the age of 15 but be perfectly fit for participation at the age of 18 when his general maturity has progressed and his muscles have been strengthened and his ligaments tightened through a carefully controlled physical education program. The routine physical examination for musculoskeletal integrity is so standardized that it does not need repetition here

On the initial examination the athlete is classified into categories of body build, strength, and physical maturity This assumes its greatest importance in the preteen age participant, where matching of opponents is essential if injury to growing tissue is to be avoided For example, 12 year-old children may vary in physical maturity between the physiological ages of 9 and 15 This does not necessarily apply to body size alone but is primarily concerned with musculoskeletal development and coordination. In a given age group either strenuous team sports or excessive

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* From Lowman, C L Faulty Posture in Relation to Performance J Health Physical Ed & Recreation 29: 14 1958.

competition in the individual sports may result in trauma from external sources or from the overloading of muscles, ligaments, and epiphyseal growth centers due to a mismatching of those at the maturity extremes. Fortunately there is a fairly good correlation between somatotype, muscular strength, physical maturity, and athletic performance which naturally segregates the more advanced physical types into the better teams. The fat stocky pyknic endomorph and the thin elongated linear ectomorph will almost routinely be more immature, weaker, and less well coordinated than the muscular "athletic type" mesomorph or the muscular-balanced mesoendomorph. Muscular strength can usually be evaluated satisfactorily by gross testing although specific muscle strength tests give more reliable information. Physical maturity can usually be classified on examination. Since skeletal bone age parallels physical maturity roentgenograms of the wrist taken for this purpose will prove of value in questionable cases. The obvious import of these tests is to ensure matching of players so that the musculoskeletal structures will not be overwhelmed by forces too great to be withstood by uncoordinated and undeveloped muscles to the extent that the capsular and ligamentous structures, together with the joints and related epiphyses, may be injured.

Examination for posture and flexibility is essential to athletic physical examination. The dynamic posture of the athlete is in sharp contrast to the semistatic posture of stance and gait. This "athletic posture" is a position of alertness and readiness in the stationary phase and one of smoothly flowing movement in running. Body control is present throughout.

The extremes of muscular effort and joint motion which are required in sports place certain implications on the interpretation of physical findings not ordinarily stressed in those with more sedentary activities. For instance what might be assumed to be a simple postural defect could be of utmost importance to the athlete both in performance and in susceptibility to injury. A typical example of this is seen in the round-shouldered individual with well-developed pectoral muscles. Here there frequently is a shortening of the pectoral muscles and the internal rotators and anterior capsular structures of the shoulder accompanied by an elongation of the posterior structures and a shortening of the anterior structures. In throwing a shortened pectoral muscle has a checkrein effect which will often cause irritation at the point of its tendinous insertion lateral to the bicipital groove because of the strong abduction extension and external rotation required. In contact sports such an individual is more likely than others to sustain anterior dislocation of the shoulder when his arm is forced into abduction, extension, and external rotation in activities such as tackling in football, for the contracted pectoralis major insertion then becomes the fulcrum of the humeral lever and tends to pry the anterior articular capsule from its glenoid attachments. Faulty trunk posture with forward head position, compensatory rounded dorsal kyphosis and lumbar lordosis and anterior pelvic tilt shifts the body weight forward to the forefoot. This predisposes to foot strains due to pronation and arch depression. In addition, if this situation becomes habitual secondary myostatic contracture may result which decreases general flexibility. In the lower back the presence of lordosis is a definite handicap for it is the function of the lower back to provide extension and lateral motion of the spine. When placed in the extended lordotic position, the facets—those anatomical doorstops of spinal motion—become locked and overriding, and the amount of possible further motion is materially reduced. Flexion contractures of the hip occur from the habitual pelvic tilt and the lower extremities tend to fall into the position of the flat footed athlete—hips and knees flexed, femur internally rotated, feet pronated—a position in which speed and agility are diminished, performance reduced, and injury likely. If the athlete is in a running sport two very definite possibilities for spinal disabilities are present. (1) The constant tug of the contracted lumbar fascia on the posterior ilium during a long forward stride may cause irritation and pain often severe enough to prevent participation. (2) The long backward stride may cause impingement and overriding of the lumbosacral facets as pelvic tilt is increased and the tolerance of the spine is exceeded. As an example, I recently saw a high school basketball player 17 years of age 81½ inches in height who came to the office complaining of back pain along the posterior iliac crest. In spite of his excellent body development and strong muscles he had a postural defect consisting of forward head position, moderately rounded back, moderate lumbar lordosis, and forward pelvic tilt. On checking him for flexibility it was found that his straight leg raising was limited at 45 degrees bilaterally both by tight hamstrings and by tight lumbar fascia. His pectoral muscles were moderately contracted and did not permit full elevation and extension of the arm. Tenderness was present at the

right posterior iliac crest near the posterior superior iliac spine. On forward bending he failed by sixteen inches to touch the floor with his finger tips. On questioning it was found that he had no particular pain in ordinary activity but that when playing basketball pain usually came on after about five minutes and was severe enough to keep him from further participation. (He ran with an extremely long stride.) He was placed on flexibility exercises for stretching of the hamstrings, lumbar fascia, and pectorals, and on general postural exercises to obliterate the lumbar lordosis, correct the pelvic tilt, and straighten the dorsal spine. Pain disappeared within a three week period and he was again able to participate without pain and with increased freedom of movement.

The examination of the skeletal system involves the spine and extremities. It should be appreciated that injury may result from either direct or indirect force and that direct blows may be either of the repeated, low-velocity impact type or of the single high velocity impact type. To give a rough example of the latter, the oncoming knee (which is regarded as the most lethal weapon in football) was tested by having a typical 185 pound fullback kick a dynamometer with the knee. Standing he could kick with a force of 500 pounds, with one step 625 pounds, and with two steps 725 pounds. Add to this the increment of forces developed by rapidly moving players and a more realistic picture is developed. The questions which the physician must ask himself are the following: (1) Can an athlete with a malaligned, deformed, weakened, or previously injured skeletal condition withstand the trauma inherent in a given sport? (2) Can he be rehabilitated to a point where he can safely return to that sport? (3) If he cannot return to his chosen sport, what alternative athletic pursuits should he be permitted to follow?

A typical example of indirect injury in the spine is cervical arthritis. This is occasionally seen in football linemen as the result of repeated low velocity impact blows from opponents. If the affliction is symptomatic and progressive the player should be eliminated from the game not only because of the danger to the neck itself but also because the anticipation of injury is likely to cause "flinching," with attendant loss of body control and coordination which makes him more susceptible to injury. In high school football players, there is a question of whether or not a boy with dorsal epiphysitis may participate. Certainly in the active stages of the disease the boy should be prohibited, for he is endangering the involved vertebral epiphyses, not only because of the natural hazards of contact sport but more especially because, with his rounded dorsal kyphosis, he has lost the normal protective mechanism—the shock absorbing flexion of the dorsal spine.

Where joint incongruity exists in the extremities, it is best to avoid sports which might subject it to abnormal stresses. For instance, an old healed, slipped upper femoral epiphysis with a deformed oval femoral head would resist rotatory stresses and place increased wear and tear on the articular surface, speeding the day when arthritic changes would develop. Definitely a patient with such deformity should avoid severe rotatory stresses such as are seen in the body contact sports and in some of the individual sports. Frequently guidance into different sports or into the use of an altered technique, in the case of the individual sports, will compensate. For instance, a 30-year-old patient came to me complaining of pain in the hip after playing golf. History and physical examination revealed an old, healed, slipped upper femoral epiphysis with a typical oval femoral head. Explanation of the cause of his difficulty and consultation with his golf instructor resulted in abandoning his attempt at pivoting actions and developing a shortened swing which was chiefly limited to shoulder and arm movement. Following this change he got along very well without further pain in the hips for a follow-up period of five years. Many similar examples could be pointed out.

TRAINING, CONDITIONING AND KNOWLEDGE OF GAME SKILLS

Once the athlete enters participation in a sport, training, conditioning and a knowledge of game skills are essential for development to a physical peak which in itself will afford protection against injury. Evidence of this is the marked decrease in the number of high school football injuries which occur when a three-week period of practice is undertaken before the first contest instead of the one- or two-week period. The well-trained player moves automatically depending upon training, instinct, and conditioning with his attention directed toward the constantly unfolding pattern of the race or contest rather than his position, posture, balance, speed, or mode of body contact. It has been shown repeatedly that individuals with superior training and conditioning are stronger, better coordinated, and less subject to injuries.

Conditioning depends upon proper muscle development, proper metabolism and motivation. Mus-

cle development is obtained by loading the muscles and pressing activity beyond the threshold of fatigue. Muscle hypertrophy follows in the same way that progressive resistance exercises will accomplish it in our physical therapy departments, but attention is directed toward the body as a whole rather than to a single muscle or muscle group. Simple repetitive actions alone give endurance but do not provide muscular strength. For this reason many athletic programs have utilized progressive resistance exercises through weight training (Table 1, page 22). The older concept that this type of excercise made an individual "muscle-bound," with marked loss of flexibility, has proved untrue. While different sports require different dominant sets of muscles, such programs are usually geared to general muscular development and the maintenance of general body flexibility. As the training program proceeds, the athlete develops a rhythm and automaticity of muscular action which allows him to accomplish his activity reflexly without thinking.

In all training programs, exercises which might prove harmful, such as the "duck walk" which is prone to injure the knee cartilages, are avoided.

Under actual game conditions in contact sports the player who is alert and moving rapidly is less likely to be injured than the player who is in a stationary fixed position (force = mass × velocity). The stationary player is usually less prepared to meet the resistance of body contact; his muscular rhythm has frequently lost its automaticity either through fatigue, loafing, or a lack of mental edge known as overtraining. The poorly coached player may be exposed to injury because of poor training and execution; the ill, injured, or physically handicapped player may be further damaged because of lack of coordination, strength, and agility. An inexperienced player who does not have a thorough knowledge of a game will frequently be injured because he simply does not know the nature of injury situations and how to avoid them. He is unaware of proper methods of falling and recovery, the safety in team cooperation and the likelihood of injury when game rules designed for safety are violated. Even should a player be properly trained and conditioned, obvious mismatching as to weight, age, maturity and experience will frequently result in injury because of the strength of the players on the prevailing team and the incoordination which occurs through fatigue and lack of desire in a team which is being overwhelmed.

PLAYING SURFACE

The actual condition of the playing surface is also of importance. Injuries will frequently occur on an irregular, bumpy playing surface where holes and hillocks are present. Grass surfaces, when thickly matted, may hang up the cleats on the shoes when the player is not adjusted to such surfaces or does not have the type of cleats adapted to the field.

PROTECTIVE EQUIPMENT

Athletic protective equipment is designed to diffuse the energy imparted by a blow over as wide an area as possible so that its concentrated effect does not exceed the tolerances of the protected structures. Its use is standardized and well outlined for each sport. Failure to use such equipment, or the misuse of it, is an open invitation to injury; employment of ill-fitting equipment falls in the same category. Examples of such protective equipment are football headgear, shoulder pads, hip pads, knee pads, baseball batting helmets, sliding pads, etc. In each instance this protective equipment affords protection only from direct blows and does not afford protection from the indirect injury.

ATHLETIC TAPING

The question of athletic taping as an aid in preventing either a primary injury or the aggravation of an old injury constantly arises (Table 2, page 25). There is no question of the protective value of ankle strapping in sports where maximum rotatory stresses are imparted to the ankle and especially when a poor playing surface is provided. The incidence of ankle sprain is generally conceded to be approximately ten times as great among players who have not used protective ankle strapping as for those who have. The statement is sometimes made in football that the tight binding of the ankle throws additional stress on the knee, subjecting it to injury. This is hardly consistent with the fact that no increased incidence of knee injury is found in other sports, such as basketball, when the ankle is taped. The effectiveness of adhesive knee strapping in ligamentous injuries of the knee is questionable. When one considers the long lever of the leg below and the thigh above imparting force to the damaged ligaments, it is scarcely conceivable that adhesive tape fixed to the skin will be of real value in resisting anything but minor ligamentous trauma; its use should be limited to convalescent treatment of knee injuries and it should not be regarded as a protective mech-

*Table 1 Weight Training Routine for All Around Development for Athletes**

Warm-Up (Without Weights)

1 Full, low flat-footed squats with arms swinging forward. When at bottom of squat position, bounce two or three times.

2 Squat and bend. First squat down from a standing position to position of full squat on toes, return to position of attention then bend forward with arms stretching toward floor and bounce three times downward.

3 Stride stand, hands on hips. Circumduct trunk first to the right and then to the left.
Do these three exercises eight or ten times each, and then.

4 Stationary run, with knees coming high as hips, till thoroughly warmed up.

Regular Exercise Routines

	Football	Basketball	Baseball	Wrestling	Swimming	Running	Hurdling	High Jump	Broad Jump	Shot & Discus	Pole Vault	Golf	Tennis	Gymnastics
†1 *S.P.*‡ Seated or squatted down with forearms resting along thighs a bar bell held just beyond the knees, with palms up. *Ex.*§ Flex hands upward. Same exercise with palms down, flexing hands backward and upward	X	X	X	X	X			X		X	X	X	X	
2 "Curls. *S.P.* Standing, bar bell in front of thighs, palms forward. *Ex.* Flex forearms completely until bar bell is just in front of shoulders.	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3 Presses *S.P.* Standing bar bell just in front of shoulders, palms forward *Ex.* "Press or thrust bar bell upward to arm's length over the head	X	X	X	X	X	X	X	X	X	X	X	X	X	X
4 *S.P.* Without weights in hands, clasp hands behind back of head, high up *Ex.* Extend head backward as far as possible giving as much resistance with hands as the neck can stand	X			XX										
5 *S.P.* Heels of hands pressing backward against forehead. *Ex.* Bend head forward against resistance of hands.	X			XX										
6 Pull-overs *S.P.* Subject supine on floor bar bell on floor beyond head, arms at full length *Ex.* With elbows straight, lift bar bell forward and upward until it is over the shoulders, and then return to S.P.	X		X	X	XX									
7 *S.P.* Bar bell resting on shoulders, behind neck. *Ex.* Execute full squats, flat-footed (Many people find this difficult to do and need to have something resting under the heels) Frequently a ten-pound bar bell will be sufficient.	X	X	X	X	X	XX	XX	XX	XX	XX	XX		X	

*Taken from material copyrighted by Dr. C. H. McCloy Research Professor Emeritus, The State University of Iowa, Iowa City Iowa.

†Exercise may be omitted if taking only a partial workout.

‡*S.P.* = Starting position

§*Ex.* = Exercise

Table 1 (Cont'd)

	Football	Basketball	Baseball	Wrestling	Swimming	Running	Hurdling	High Jump	Broad Jump	Shot & Discus	Pole Vault	Golf	Tennis	Gymnastics
8. *S.P.* Bar bell resting on shoulders behind neck, or held in hands in front of thighs. *Ex.* Rise on toes. (It may help to have a plate on the floor under the toes, thus giving a greater distance over which to rise.)	X	X	X			XX	XX	XX	XX	XX	XX		X	
9. *S.P.* Standing with dumbbells in hands beside thighs. *Ex.* Raise dumbbells sideward to a position about 45 degrees above the shoulders. If different weights of dumbbells are available do three sets of exercises, increasing the weight each time	X	X	X	X	X	X	X	X	X	XX		X	X	X
10. *S.P.* Standing with dumbbells beside thighs. *Ex.* Raise dumbbells forward to a position of about 45 degrees above level of shoulders. Do three sets of these	XX	X	X	X		X	X	X	X	XX	X		X	X
11. *S.P.* Trunk bent forward until it is parallel to the ground, back straight. *Ex.* Swing dumbbells from a position downward in front of the shoulders to the side horizontal position, and as far backward as possible. Do two sets of these exercises.			X	X	X							X	X	
12. *S.P.* Lying on bench face up, arms at right angles to the trunk, above the shoulders. *Ex.* Swing dumbbells from that position to a position out at the side and as far down toward the floor as possible. Do two sets of this exercise.	X		X	X	X	X	X	X	X	XX		X	X	X
13. *S.P.* Using a very heavy bar bell, have someone lift this until the performer holds it at arm length (in a supine position) in front of shoulders. *Ex.* Keeping arms straight, push the bar bell upward as far as possible	X		X							XX		X	X	X
14. *S.P.* Performer should, if possible, be lying on a slanting abdominal board with feet upward. If no board is available do same exercise on the floor with feet held down. *Ex.* Holding a plate (as heavy as the individual can manage) behind the neck, do sit-ups.	X			X		X	X	X	X	XX	X	X	X	XX
15. *S.P.* Lying on floor, no weights involved. *Ex.* Do abdominal curls. Here with hands on front of thighs (face up) with lower back in contact with the floor, "curl" trunk forward, pushing hands down the thighs, attempting to touch the knees or even go below	X		X	X	X	X	X	X	X	XX	X	X	X	XX

Table 1 (Cont'd)

	Football	Basketball	Baseball	Wrestling	Swimming	Running	Hurdling	High Jump	Broad Jump	Shot & Disc	Pole Vault	Golf	Tennis	Gymnastics
†16. "Walking squats." *S.P.* Performer standing with bar bell behind neck. *Ex.* Performer takes a step about a foot or a foot and a quarter in length forward with one foot and then squats down on the rear heel. Upon rising, he strides forward with the opposite foot and repeats and continues this movement.	X	X	X	X		XX	XX	XX	XX	XX	XX		X	
17. *S.P.* Standing, bar bell held in front of thighs. *Ex.* Bend forward with knees almost straight *until bar bell rests on floor. Return to position.*	X			X						X				X
18. Do *one* of the following two exercises. (a) With dumbbells in hands jump one foot forward and the other foot backward ("splits"). In the forward leg the knee is bent at least to a right angle; back leg is straight. Jump to reverse position without coming to an erect position. Do this continuously until winded.	X			X	X		X	X						X
(b) With bar bell on floor, knees bent, performer bent over, snatch bar bell upward to arm's length overhead, with one leg going forward and the other backward as in Exercise 18a, immediately above.	X			X	X		X	X						X
19. *S.P.* Using bar bell about ½ to ⅔ the weight of that used in Exercise 17, with bar bell behind head, knees straight. *Ex.* Bend forward and downward with back straight, and "bob" downward or "bounce" three times.				X						X				X
20. *S.P.* Feet in stride stand, trunk bent forward to right angle (back straight), dumbbells in hands straight down toward floor from shoulders. *Ex.* Rotate trunk to left and bounce three times. Same to opposite side.	X		X	X			X			XX		X		
If iron boots with weights are available, perform the following two exercises.														
†21. Seated, lower leg hanging down from knee, extend lower leg fully.	XX					X	X	X	X	X				
†22. Standing with opposite foot on a box or platform, leg with boot hanging down, flex lower leg backward as far as possible.	XX					X	X	X	X	X				

Table 1 (Cont d)

	Football	Basketball	Baseball	Wrestling	Swimming	Running	Hurdling	High jump	Broad jump	Shot & Discus	Pole vault	Golf	Tennis	Gymnastics
23 With light bar bell or dumbbells in hands, swing forward and downward from position with bells overhead exhaling, then forward and upward to position overhead inhaling Exhale and inhale fully This exercise is primarily for increasing the strength of the muscles of respiration.	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Suggestions

1 With all except Exercises 16, 18, and 23 the performer should use a weight heavy enough so that he can lift it only about eight times.

2. In doing Exercises 9 through 12 with dumbbells, if doing more than one set, the first set can well be done with heavier weights that can be lifted (at the beginning) only eight times. In the third set as many exertions as possible should be made The performer might by that time be so fatigued as not to be able to do the fully prescribed number

3. It is frequently advisable on all of the lifts that are not fast lifts to hold the return of the last lift, halfway through its range, for full six seconds The performer can estimate six seconds by counting "one second, two seconds, six seconds This frequently increases the strengthening effect of the exercise.

4. Where the term "bounce is used, the individual swings to the end of the movement and then endeavors three times to move the bell further in that direction.

5 Throughout this type of weight-training exercise, the individual should *not* cut off his breathing (close the glottis) He should, in general, inhale on upward movements and exhale on downward movements. The inhalation and exhalation should be rather marked, though not necessarily to the full limit of inhalation and exhalation except on the last exercise.

6. The full workout should not be done more often than three times per week.

Table 2 Summary of Athletic Taping Methods

Region	*Indications*	*Contraindications*	*Principle*	*Position of Strapping*	*Evaluation*
			Upper Extremity		
Shoulder joint	1 Contusion 2 Sprain 3 Rotator cuff injury	1 Fracture 2. Dislocation	1 Lift to draw upper arm into shoulder joint 2. Axillary pad to prevent dropping of underaspect of shoulder joint	Abduction 60 degrees Forward flexion 45 degrees	Effective for minor injuries
Acromioclavicular joint	Sprain	1 Dislocation 2 Fracture	1 To maintain joint in normal position by: ( ) Downward pull on clavicle (b) Upward lift on arm 2 To splint shoulder	Joint held so that superior joint ligaments are relaxed	Effective for partial immobilization of minor strains

(Continued on next page)

Table 2 (Cont'd)

Region	*Indications*	*Contraindications*	*Principle*	*Position of Strapping*	*Evaluation*
Elbow	Hyperextension sprains and strains	1. Fracture 2. Dislocation	To prevent hyperextension by (a) A piece of tape anchored at wrist and upper arm, spanning flexed elbow and acting as check rein to extension (b) Cruciate strips crossing just medial to biceps tendon and anchored to forearm and upper arm	60 degrees of flexion, elbow full supination	Effective in preventing last 30 degrees of extension
Wrist	General support (ineffective for sprain)	Severe sprain or fracture	Circular tape binding of wrist	Neutral position of function	Ineffective: palliative value only
Fingers and hand	1. Strain of flexor muscles 2. Anterior sprain, wrist	1. Fracture 2. Dislocation	To prevent extension of wrist and fingers, by anterior tape from finger tips to upper forearm	Fingers slightly flexed Wrist flexed 40 degrees	Effective in preventing extension beyond 20 degrees of palmar flexion; can be worn only a few hours
Thumb	Sprain, base of hand	1. Fracture 2. Dislocation	To prevent abduction of thumb: (a) Figure-of-8 strapping of thumb with circular wrist anchor (b) Strapping thumb to index finger (c) Gauztex or ankle-wrap thumb spica	Neutral rest position	Protects against extremes of abduction and extension of thumb
			Lower Extremity		
Toe	1. Sprain, metatarsophalangeal joint secondary to forced dorsiflexion (toe-up position) 2. Contusion	1. Fracture Dislocation	To restrict motion at base of toe by application of three basic adhesive strips extending from end of toe to mid-longitudinal arch	Neutral 180 degree position	Partial, temporary immobilization for minor trauma
Longitudinal arch	Arch strain (most commonly found in players with high arches follows running on hard surfaces and changing of shoes)	None	To restore height of arch by pulling ball of foot to heel and by use of arch pads	Foot in plantar flexed position (dropped down) and arch at maximum height	Satisfactory for short term use
Ankle	1. Prevention of sprain 2. Prevention of resprain 3. Treatment of mild acute and convalescent ankle sprains	1. Fracture 2. Dislocation 3. Severe sprains	1. To lock heel in everted or valgus position 2. To draw forefoot into everted and slightly pronated position	1. Foot at or above 90 degree position 2. Eversion of forefoot to position of relief for patient	Effective when properly applied

Table 2 (Cont'd)

Region	*Indications*	*Contraindications*	*Principle*	*Position of Strapping*	*Evaluation*
Calf muscles and Achilles tendon	Mild strain (usually at musculotendinous junction)	1. Complete or partial rupture of tendo achillis 2. Severe strain with marked swelling	To hold foot in plantar flexed position by means of: (a) Tape extending down back of leg to ball of foot (b) A heel pad of vinyl plastic or sponge rubber (c) A reinforcing ankle taping	Athlete in prone position with foot in plantar flexed position	Effective for short periods in mild cases
Shin	1. Strain of extensor muscles of lower leg at their point of bony and soft tissue attachment 2. Treatment of mild to moderate cases		Splints to place extensor muscles at rest by restriction of dorsiflexion by: (a) Restricting upward movement of foot, and (b) Restricting expansion of leg during muscle contraction	Moderate plantar flexion (drop foot position)	Effective in some mild cases
Calf	Mild to moderate contusions	Severe contusion with swelling	Sponge rubber compression over injured area fixed by tape leaving 1" open area in front of leg and extending from ankle to 3" above injured area	Relaxed drop foot position	Affords fair compression on ambulatory basis
Knee	1. Mild or convalescent knee sprains with good range of motion and strong quadriceps muscles	Moderate or severe sprains with partial or complete ligamentous tears	Utility strapping of knee to maintain bony alignment by use of cruciate adhesive strips over medial and lateral sides of knee, extending from mid-leg to mid-thigh with tension on side of injured ligament	Knee in 30 degree flexion	Limited effectiveness; does *not* afford sufficient protection to permit participation, in moderate to severe sprains
	2. Mild anterior cruciate ligament sprains	Severe knee sprain	Felt reinforcement strapping. A piece of felt is placed on back of knee to afford a splinting effect and limit flexion; this is fixed with tape above and below knee	Knee in 30 degree flexion	Limited effectiveness; does *not* afford sufficient protection to permit participation, in moderate to severe sprains
Thigh	1. Contusion 2. "Charley horse" (thigh contusion with hematoma)	Severe contusion	Criss-crossed tape encircling anterior two-thirds of thigh; a compression pad may be added	Full extension of knee with thigh relaxed	Affords moderate compression for ambulatory cases
Hamstring	Mild to moderate strain or spasm	Severe strain	Restriction of extension of knee by posterior (back) adhesive strips extending from just below fold of buttocks to mid-calf	45 degree flexion	Restricts extension of knee at 150 to 160 degrees; applied for a few hours only
Adductor muscle (groin)	Strain of adductor muscles at their insertion		Compression dressing of felt, fixed by adhesive plus an elastic bandage spica about thigh and pelvis	20 degree abduction of hip; standing position	Affords moderate ambulatory compression

anism. Injury to the knee probably deserves special mention, since it is the most vulnerable target for injury because of its exposed position and the fact that its movements are largely restricted to flexion and extention with a relatively small amount of rotation and little medial or lateral give. Of the contact injuries of the knee in football 63 per cent occur from the side 28 per cent from the front, and only 9 per cent from the rear To sustain such a ligamentous injury the foot must be fixed to the ground so that the force of the blow levers the joint apart with the outer bony rim acting as a fulcrum It is obvious that avoidance of such injury is dependent upon proper coaching so that the athlete has complete body control at all times and constantly keeps his feet moving to avoid anything more than momentary contact with the ground. Noncontact trauma usually results from twisting injuries when the player suddenly changes direction (cutting in football) and overstrains the knee either because of loss of body control or because of poor footing on the playing surface.

In summary the prevention of athletic injuries is dependent upon (1) the pre participation physical examination which makes it possible to disqualify the unfit and rehabilitate the athlete with correctible musculoskeletal defects (2) the classification of players according to age weight, maturity and physical ability (3) adequate training conditioning and coaching and (4) the use of proper protective equipment and the provision of good playing conditions. Medical decisions which affect the athlete's future welfare should not be swayed by the eagerness of the player the desires of the coach, or the clamor of public enthusiasm.

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INJURIES TO THE KNEE

The acute traumatic knee is a diagnostic problem that demands every facility of clinical and laboratory methods for exact and immediate diagnosis. It is not tenable to casually inspect a traumatized knee suggest rest and local heat and request re examination in a week or so if the knee "still bothers."

As in all diagnostic problems, a careful history of past injuries or disability must be elicited. Prior ligamentous instabilities, recurrent locking episodes et cetera must be accurately ascertained to determine correctly the extent of the current injury An accurate knowledge *of the mechanism of the injury* aids one in determining the extent of force exerted toward the knee in a specific manner Possible injury sites can be determined prior to examination. A force exerted against a knee may produce a multitudinous variety of injuries, depending upon direct violence to either a stationary or a moving knee extreme indirect leverage forces exerted, if the foot and/or hip are fixed extreme forces of torsion or a combination of these many mechanisms. Fractures occur with severe dynamic forces, but usually not in combination with ligamentous injury

Physical examination must include inspection of both entire legs immediately following the injury Unless a fracture deformity is present there may be very little deformity about the knee in spite of rather extensive ligamentous damage. The exact extent of local tenderness about the knee and the presence or absence, of an effusion or hemarthrosis can be detected without moving the extremity Determination of the range of motion and the stability of a knee can be *carefully and gently* carried out without causing the patient great discomfort. It is usually too painful to flex the knee enough to determine cruciate stability when an injury is extensive Roentgenographic examination is mandatory in the anteroposterior and lateral projections. If suspicious areas are visualized oblique projections, open joint techniques, and even laminographs are sometimes necessary to accurately determine pathology

ACUTE INJURY TO SOFT TISSUE

The following outline lists the multitudinous injuries to soft tissue, *which will be discussed.*

1 Effusion
2 Hemarthrosis
3. Prepatellar effusion and/or hemorrhage
4 Ligamentous injury (collateral or cruciat ligaments)
   (a) Strain
   (b) Incomplete rupture
   (c) Complete rupture
   (d) A ulsion of attachment
5 Meniscal injury

It is important to realize that an effusion or a hemarthrosis is usually not an entity of itself but is a mirror reflecting damage to the joint. A traumatic effusion and/or hemarthrosis accompanying a mild ligamentous injury but without severe ligamentous injury or fracture necessitates rest and, initially cold applications followed by local heat after twenty four hours. Aspiration of the joint may be necessary if the effusion is tense and painful. A temporary period of several days of immobilization should suffice as the tissue trauma is mild A constant effort must be made to maintain

muscle tone during this entire period. The use of a local anesthetic such as procaine with or without the adjunct use of hydrocortisone is reserved for a localized area of residual tendinitis many days after the injury. If this procedure is used judiciously convalescence is greatly enhanced. The procedure is to be condemned if its use is in lieu of the well-accepted surgical principles of rest and immobilization during the acute traumatic period. A similar regime of treatment is adequate for effusion and/or hemorrhage in the prepatellar bursa.

Any force exerted against a knee that exceeds both the active stabilizing element, the musculature, and the passive stabilizing element, the ligaments, will strain, incompletely rupture or avulse the attachment of one or more of the major ligaments. Fig. 1 dramatically illustrates a mechanism of severe ligamentous injury which resulted in a complete laceration of the superficial tibial collateral ligament, avulsion of the femoral attachment of the deep tibial collateral ligament, and avulsion of the tibial attachment of the anterior cruciate ligament. Injury to the cruciate ligaments is relatively uncommon in comparison to injury of the collateral ligaments. Diagnosis of the extent of injury to the collateral or cruciate ligaments is mandatory before initiating

Fig. 1 Photograph of base runner spoiling a double play. Mechanism of injury resulting in tear of tibial collateral ligament and avulsion of anterior cruciate ligament. (Wide World Photos Inc. from Milwaukee Sentinel Aug. 4 1958.)

any definitive therapy. Extreme tenderness along the course of the collateral ligaments indicates the magnitude of injury and at times an actual rent in the region can be palpated if examination is possible immediately following the injury. Examination under anesthesia may be a necessary procedure to determine absolutely the stability of the injured knee. Muscle spasm and pain can prevent pathological excursion of the knee even in those cases with complete dissociation of the ligaments. This is especially true for examination of cruciate stability. It is acceptable and justifiable to examine a knee under anesthesia and if instability is present, proceed with an immediate surgical repair.

Moderately severe ligamentous injury and/or incomplete rupture demands adequate sedative care as outlined previously. The more extensive damage of the ligaments demands a more prolonged period of immobilization and cast fixation is advised. Associated with the more prolonged immobilization, the need for greater attention to maintenance and rehabilitation of muscle tone is obvious.

Complete rupture of the collateral ligaments and/or cruciate ligaments demands immediate surgical repair. It is well accepted that if one of the major ligaments is torn the ends are dissociated and they do not heal in accurate apposition unless they are manually repositioned by surgical manipulation and suture.

An anteroposterior roentgenogram (Fig. 2) typically demonstrates the abnormal mobility of the knee during examination under anesthesia in a patient with a complete rupture of both the tibial collateral and the anterior cruciate ligaments. Not only does a gap between the lacerated ends functionally lengthen the ligament and diminish its stabilizing effect, but also the interposing scar tissue is of much less tensile strength than accurately sutured opposing ends. In many cases one end of the ligament has been displaced into the joint, in a complete loss of contact with the other fragment and complete loss of stability. Cruciate ligaments are seen to fall flaccidly onto the tibial plateau in total dissociation.

An anteroposterior roentgenogram (Fig. 3) demonstrates the abnormal mobility of the knee during examination under anesthesia in a patient with complete rupture of the lateral or fibular collateral ligament and an avulsion of the biceps femoris tendon attachment. Avulsion of the attachment of a major ligament produces an immediate, complete loss of functional stability of that ligament. The dynamic force producing the avulsion displaces the avulsed

Fig. 2. Anteroposterior roentgenogram demonstrating instability of knee under anesthesia, with complete tear of tibial collateral and anterior cruciate ligaments.

Fig. 3. Anteroposterior roentgenogram demonstrating instability of knee under anesthesia with complete tear of fibular collateral ligament and avulsion of the attachment of the biceps femoris muscle.

ends at some distance from the attachment and thus must be actively surgically repositioned and fixed as there is no force intrinsic within the ligament to restore its normal attachment.

Emphasis on these principles can be made diagrammatically by promulgating O'Donoghue's "unhappy triad" (Fig. 4). Adequate surgical repair is effected by removal of the torn medial meniscus (Fig. 5) plus surgical repair of the lacerated anterior cruciate and tibial collateral ligaments. The diagnosis must be made. Adequate surgical repair follows well-founded surgical principles.

The diagnosis of injury to the menisci can be exceedingly difficult during the acute traumatic phase because of a generalized response of the entire joint to injury. The diagnosis at any time can be difficult because of the multiplicity of pathological entities that can occur. Speed and Knight have classified meniscal tears as follows:

1. Rupture or tear: (a) longitudinal or classical bucket-handle, (b) transverse, (c) oblique
2. Tear of the peripheral attachments: (a) posterior horn, (b) middle attachment, (c) anterior horn
3. Combined tears of the periphery and of the body of the meniscus
4. L-shaped or pedunculated tears of the semilunar cartilage
5. Frayed or shredded concave edge*

A history of rotation injury that occurs when force is exerted against a knee while the foot is locked into the ground with long cleats is most typical. The rotation forces bring one or the other meniscus beneath its corresponding femoral condyle and when extension of the knee occurs, the meniscus is impaled and torn. The greater incidence of injury to the medial meniscus is related to the axis of rotation about the medial femoral condyle and the more frequent abduction forces applied laterally by body contact. Clinically one recognizes an early effusion and/or hemarthrosis because the insult is intra-articular in nature. Localized tenderness is present at the site of injury along the tibial plateau. *Motion* of the joint may not be especially painful, not more than might be expected with the degree of joint distention. The cardinal sign of "rubbery resistance" to complete extension may or may not be present, depending on whether displacement of the torn fragment exists at the time of examination.

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*From Speed, J. S., and Knight, R. A.: Campbell's Operative Orthopaedics, ed. 3, The C. V. Mosby Co., p. 339.

Fig. 4. O'Donoghue's "unhappy triad." (From O'Donoghue, D H. J Bone & Joint Surg. 32-A: 721 1950.)

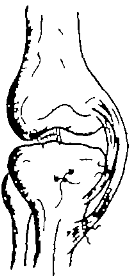

Fig 5. Diagram of surgical repair of "unhappy triad. (From O'Donoghue D H. J Bone & Joint Surg. 32-A: 721 1950.)

It is mandatory to treat these knees expectantly at first, as related above, for the obvious insult to the joint and, as the generalized traumatic reaction subsides, the localizing signs will become more apparent. A firm diagnosis of a "locked knee joint secondary to a torn meniscus *is an indication for arthrotomy* and removal of the meniscus. The poor healing power of the meniscus following laceration does not warrant the articular tissue trauma of attempts to forcefully reduce the torn meniscus. If the joint "unlocks" spontaneously during the sedative therapy program, advantage should be taken of this good fortune and cast immobilization used with the hope for sufficient healing to avoid arthrotomy

ACUTE INJURY TO BONE

The following outline lists acute injuries to bone seen in trauma about the knee.

1 Extra-articular fractures
 (a) Supracondylar fracture
 (b) Distal femoral epiphysis
 ( ) Proximal tibial epiphysis
2 Intra-articula fractures
 ( ) Tibial plateau
 (b) Tibial spine
 (c) Patella
 (d) Flake fracture of articular surfaces

The acute damage to bone in injuries about the knee also presents a diagnostic problem. Extra articular fractures present deformity about the knee, with the immediate total disability abnormal mobility crepitus et cetera, with which we are familiar There is usually sufficient gross displacement of the fracture fragments to confirm the diagnosis by the usual anteroposterior and lateral roentgenograms.

Interestingly the varied forces exerted against a knee can be illustrated by a variety of displacements of the epiphyses. *A fracture of the distal femoral* epiphysis (Fig 6) was secondary to a severe force, probably exerted to the lateral aspect of the knee, as in a "blocking maneuver" A complete displacement of the distal femoral epiphysis (Fig 7) was probably the result of a dynamic force in hyper extension. An acute, severe flexion attitude of the knee probably caused the anterior displacement of the proximal tibial epiphysis (Fig 8)

Intra-articular fractures about the knee include the usual fractures of the patella and of the tibial pla teau Again, these fractures are usually confirmed by the anteroposterior and lateral roentgenograms *included in a diagnostic work up The multiplicity of* forces about the knee also produce a variety of unusual intra-articular fractures that are many times exceedingly difficult as diagnostic problems. Intra articular fractures about the knee provoke an im mediate hemarthrosis. This may be the key to the diagnosis of a severely disabling knee injury which cursory examination indicates to be less severe than the extent of disability implies These knees demand extensive roentgenological survey with varied techniques and positions until a diagnosis is made

Osteochondral or flake fractures of the articular surfaces of the knee joint are the result of forceful

Fig. 6. Anteroposterior nd lateral roentgenograms of distal femoral epiphyseal fracture the result of football block.

Fig. 7. Anteroposterior nd lateral roentgenograms of distal femoral epiphyseal fracture the result of hyperextension injury in football (From Blount W P., Fractures in Children, Baltimore 1954 Williams & Wilkins Co.)

Fig. 8. Anteroposterior and lateral roentgenograms of proximal tibial epiphyseal fractur the result of severe flexion injury

Fig. 9. Anteroposterior roentgenogram of osteochondral fracture lateral femoral articular surface (From Brewer B J S Clin North America 38 1137 1958.)

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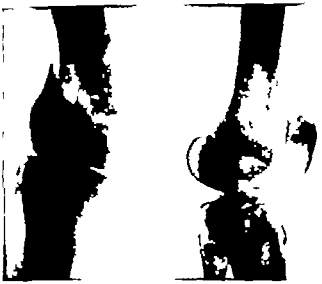

Fig. 6. Anteroposterior and lateral roentgenograms of distal femoral epiphyseal fracture the result of football block

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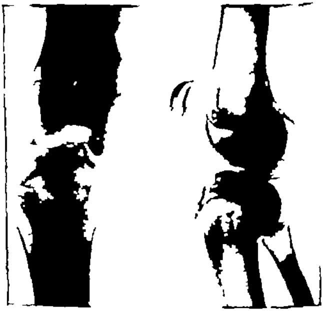

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Fig. 9. Anteroposterior roentgenogram of osteochondral fracture lateral femoral articular surface. (From Brewer B J S Clin. North America 38: 1137 1958)

shearing contact between the femur and the tibia, resulting in avulsion of a fragment of the articular cartilage and usually the underlying subchondral bone. There is, of course, an inverse ratio to age, in the size of the cartilaginous fragments, and in the younger patient a displaced, minute fracture shadow may mean a large displaced fragment of cartilage. Surfaces avulsed completely act as loose bodies in the joint, and mechanical locking of the joint secondary to these loose bodies demands arthrotomy. Large defects in weight-bearing areas may warrant repositioning and local fixation. A typical example of the above, an anteroposterior roentgenogram (Fig 9) demonstrates an avulsion osteochondral fracture lateral aspect of the distal femoral articular surface, which is displaced and lying medially in the joint in the region of the tibial spine. The fragment *in its displaced position is designated by an arrow* as is the site of origin. Arthrotomy was performed and the loose body was removed.

Fracture of the anterior tibial spine (Fig 10) in children is of special consideration. The fracture is an avulsion fracture of the bony attachment of the anterior cruciate ligament and results in instability with a typical anterior drawer sign. Arthrotomy was performed in this case and the fracture fragment reseated in its bed and held with a stainless steel wire as demonstrated (Fig 11)

Fig. 10. Lateral roentgenogram of avulsion fracture anterior tibial spine with resultant anterior cruciate ligament instability (From Brewer B. J S. Clin. North America 38: 1137 1958)

Fig. 11 Anteroposterior and lateral roentgenograms of surgical repair reseating bone fragment and metal wire fixation. (From Brewer B J.: S. Clin. North America 38: 1137 1958.)

Many entities of trauma about the knee have been presented. Maximum recovery should be achieved by a diagnosis that is exact and treatment that is based upon good orthopaedic judgment and well-founded surgical principles.

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DIAGNOSIS AND TREATMENT OF ANKLE INJURIES SUSTAINED IN SPORTS

The doctor who assumes responsibility for a group of athletes is in a unique position to study trauma. Circumstances are ideal for observation of injury from the moment of occurrence to full recovery. In sports involving quick pivoting on a fixed foot, such as football, soccer and basketball, or unanticipated wrenching with a lever, as in skiing, a high proportion of injuries will involve the ankle.

The incidence of injury can, of course, be reduced by physical conditioning and acquisition of skill in the techniques of the sport. It is a truism that the outstanding athlete is rarely injured, and then only under unusual circumstances. But not all participants in active sport are neuromusculoskeletal geniuses, nor do they have the time to become technical virtuosos.

For these, a considerable measure of protection is afforded by regular use of ankle wraps.[1]

Applied over the inner of two pairs of socks, with a turn around the heel (Fig. 12), these nonelastic bandings, which the player applies himself, effectively limit lateral mobility without interfering with flexion or extension. When required of all players at all practice sessions and games, the incidence of ankle injuries can be reduced at least 50 per cent.[2]

But despite conditioning, ankle wraps, and skillful coaching, ankle injuries still occur, and the doctor's duty begins at the moment of injury. He should himself go onto the playing field and decide whether the injured player should continue play or leave the game and, if he leaves, whether he walk or be carried. To leave such decisions to a coach or trainer is to gamble on future disability with the cards stacked against the player. The doctor's authority in these and other medical matters should be absolute and unquestioned. Practically all coaches today are quite happy to be relieved of this responsibility. They have enough difficult decisions in their own field.

Once off the playing field a preliminary survey can be made. All that can be accomplished at this time is differentiation between major and minor injury. Minor injury means sprain or incomplete rupture of ligament; major injury means fracture or complete ligament rupture, or both. Almost invariably anteroposterior and lateral roentgenograms will be necessary. Even the most experienced examiner cannot be certain of the presence or absence of fracture or widened joint mortise by palpation and inspection alone. It is better to take fifty negative roentgenograms than to miss one serious injury.

Accumulated evidence—from observation of the mechanism of the injury as it occurred, the location of pain, tenderness, and swelling on examination, and the type of fracture and state of the joint mortise shown on x ray—should be enough to establish a precise diagnosis of major bone and ligament injury. Fracture is, of course, obvious in the x ray films, but the diagnosis of complete ligament rupture can be more subtle and, if not recognized, can be at least as serious as fracture in terms of future disability. For practical purposes, only three ligament complexes need be considered: the medial collateral (or deltoid), the tibiofibular-fibulotalar, and the lateral collateral (or fibulocalcaneal).

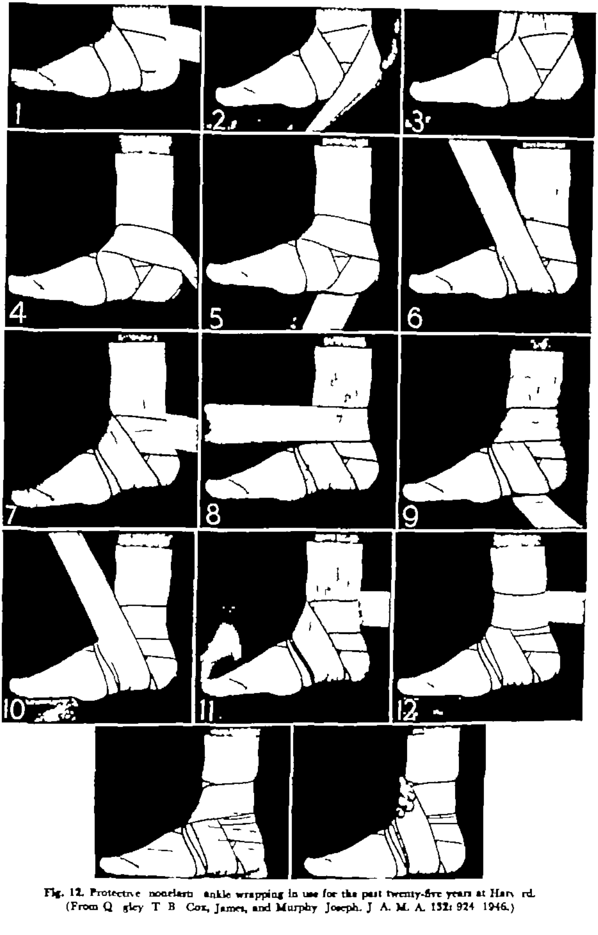


Fig. 12. Protective nonelastic ankle wrapping in use for the past twenty-five years at Harvard. (From Quigley, T. B., Cox, James, and Murphy, Joseph. J. A. M. A. 132: 924, 1946.)

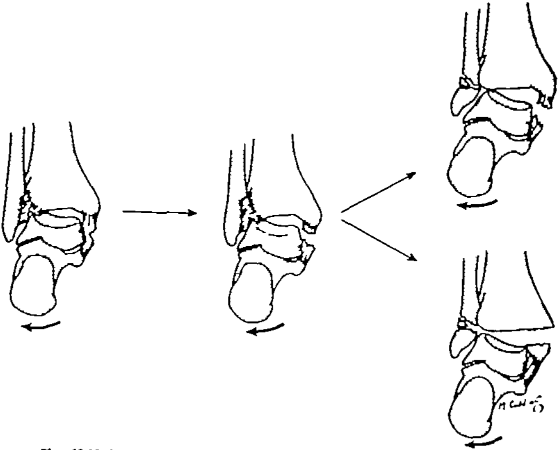
Most severe ankle injuries sustained in sports are of the abduction-external rotation type in which the talus twists and pries the fibula from the tibia. Either the fibula itself fractures, or the anterior tibiofibular ligament ruptures, producing widening of the tibiofibular syndesmosis (Figs. 13 to 16). In either event, as force continues, the deltoid ligament gives way (or more rarely in young men pieces of the medial malleolus of varying size are avulsed) and the joint space between the talus and the medial malleolus can be seen to be wider than the horizontal component of the ankle joint.

Fracture accompanies ligament rupture more often than not, and the type of fracture, as Lauge Hansen has pointed out is a most valuable key to diagnosis (Figs. 17 and 18).

Internal rotation adduction forces can stretch only the fibular collateral ligament, the others being compressed, and then only if the characteristic horizontal avulsion fracture of the lateral malleolus does not occur. Isolated injuries to this fibulocalcaneal ligament system even when severe rarely require primary open surgical repair and manipulation for diagnostic purposes immediately after injury is not often necessary. Only when severe lateral ligament injuries are neglected and subjected to repeated re injury does the characteristic tilt of the talus occur on reproduction of the original stresses (Fig. 19). For these the elegant reconstructive procedure of Watson Jones,[4] utilizing the peroneus brevis tendon has proved most satisfactory.

Analysis of ankle injuries sustained in sports should not require much time and advantage can often be taken of the twenty to thirty minutes after injury before edema, hemorrhage and spasm occur and during which nature imposes analgesia, to accomplish closed reduction of even grossly displaced fractures with almost no discomfort.

For external rotation abduction injuries in which the medial malleolus is intact the simple device of suspending the stockinette-encased limb has proved most helpful. With the gastrocnemius relaxed by



Figs. 13-16. Mechanisms of ankle injuries (after Lauge-Hansen).
Fig. 13. Pronation—abduction. (From Quigley T B : J. A. M. A. 169: 1431, 1959.)

flexion of the knee, the ankle naturally falls into adduction, moderate flexion, and supination, reversing the mechanism of injury (Figs. 19 and 20) Often little or no manipulation is required (Figs. 21 and 22) to achieve excellent reduction of grossly displaced fractures. If after suspension or manipulation, or both, the mortise is still widened, it can be assumed that the torn deltoid ligament is trapped between the talus and the medial malleolus, and prompt surgical reconstitution is indicated.

The problem is not solved, however by a perfect, closed reduction of the fibular fracture and restoration of the widened mortise to normal. The torn ends of ligament and capsule are not within the joint but are they in perfect position, or are they twisted and rolled in such a way as to heal with poor strength and function? The matter can be settled only by surgical exploration, which is quite justifiable unless contraindications such as the extremes of age, poor circulation, or poor skin are present. Most ankle injuries of such severity as to require splinting should be immobilized in a cast extending to the groin, with the knee flexed 30 to 40 degrees.

Displaced bimalleolar or trimalleolar fractures in young athletes almost always require operation. Precise closed reduction is difficult, since no fixed point remains on which to hinge manipulation, and interposed soft tissue between the fragments of the medial malleolus is the rule rather than the exception. Little less than anatomical perfection can be accepted in these severe multiple ligament and bone injuries, since these young men have at least five decades of use of their ankles ahead of them. Only the most trivial fractures, not involving ligaments, can safely be treated by a short leg boot and weight-bearing device. Torsion within a walking boot can displace even the common, and usually uncomplicated, external rotation fracture of the distal fibula, since concomitant injury to the deltoid ligament can be more severe than originally appreciated.

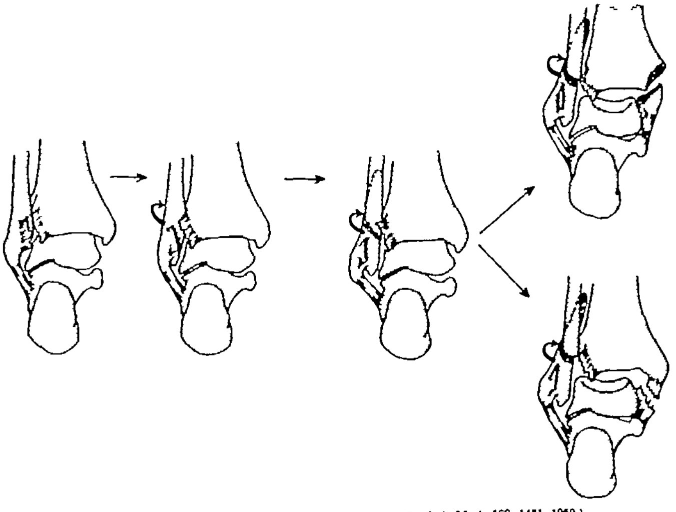


Fig. 14 Supination—external rotation. (From Quigley T B J A. M. A. 169: 1431 1959)

If at the first examination within moments of injury the damage is determined to be minor four principles of treatment are instituted *cold compression rest* and *elevation* These are based on the concept that a sprain is a partial tear of a ligament with hemorrhage at the point of tear absorption of the resulting hematoma, and replacement of the gap by fibroblastic scar The process is the same as the healing of any sterile wound. No method has yet been found to accelerate the process beyond nature's rate but many are available which slow it down or disturb the end result. These include the use of procaine hydrocortisone rough manipulation and massage, and "running it out." *Cold* promptly applied constricts the arteriolar bed and limits the hematoma. *Compression* disseminates the hematoma already present and speeds its absorption by increasing its surface area. *Rest* is an obvious need. As in any injury whatever motion hurts is wrong whatever does not hurt is right. *Elevation* minimizes the edema of dependency and disuse At this first examination when the injury has been determined to be a sprain and not a ligament rupture or fracture a bevelled doughnut of foam rubber of the tan open-call type 2 cm in thickness, is placed over the injured side of the ankle with the malleolus in the aperture (Fig 23) The skin is protected from direct contact with the rubber by sheet wadding The rubber is then compressed to about half its thickness with an elastic cotton bandage extending from the toes to the upper calf The limb is next immersed in cold (40° F) water or packed with ice bags for thirty minutes. The wet dressing is then replaced crutches are fitted and the player is instructed in their use. He is advised to spend as much time as possible during the next twenty four hours with the ankle elevated above the level of the heart.

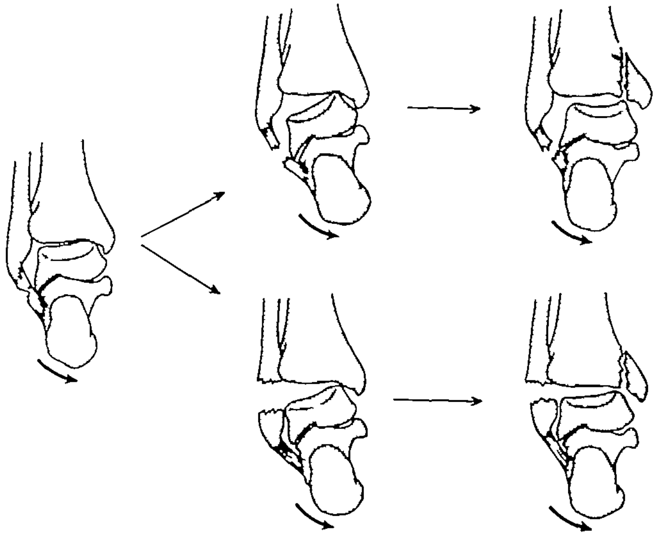


Fig. 15. Supination—adduction. (From Quigley T B. J A. M. A. 169: 1431 1959)

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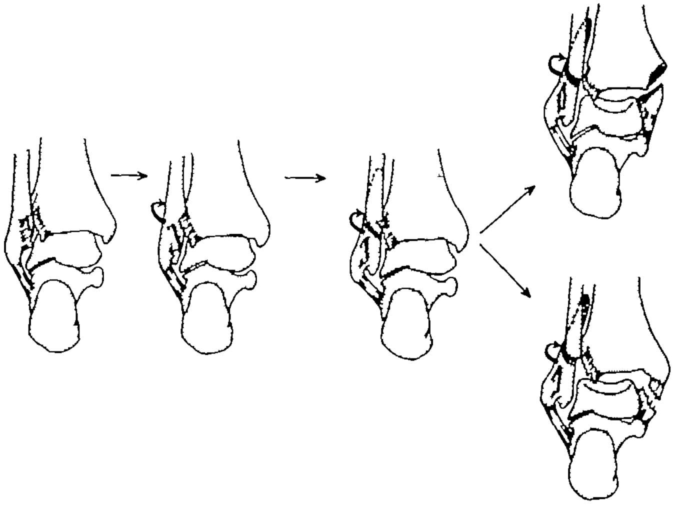

Fig. 14 Supination—external rotation. (From Quigley T B J A M A 169: 1431 1959)

If at the first examination within moments of injury the damage is determined to be minor four principles of treatment are instituted *cold compression rest* and *elevation* These are based on the concept that a sprain is a partial tear of a ligament, with hemorrhage at the point of tear absorption of the resulting hematoma and replacement of the gap by fibroblastic scar The process is the same as the healing of any sterile wound. No method has yet been found to accelerate the process beyond nature's rate, but many are available which slow it down or disturb the end result. These include the use of procaine hydrocortisone rough manipulation and massage, and "running it out." *Cold* promptly applied constricts the arteriolar bed and limits the hematoma *Compression* disseminates the hematoma already present and speeds its absorption by increasing its surface area. *Rest* is an obvious need. As in any injury whatever motion hurts is wrong whatever does not hurt is right. *Elevation* minimizes the edema of dependency and disuse At this first examination, when the injury has been determined to be a sprain and not a ligament rupture or fracture, a bevelled doughnut of foam rubber of the tan, open-cell type 2 cm. in thickness, is placed over the injured side of the ankle with the malleolus in the aperture (Fig 23) The skin is protected from direct contact with the rubber by sheet wadding The rubber is then compressed to about half its thickness with an elastic cotton bandage extending from the toes to the upper calf The limb is next immersed in cold (40° F) water or packed with ice bags for thirty minutes. The wet dressing is then replaced crutches are fitted and the player is instructed in their use. He is advised to spend as much time as possible during the next twenty four hours with the ankle elevated above the level of the heart.

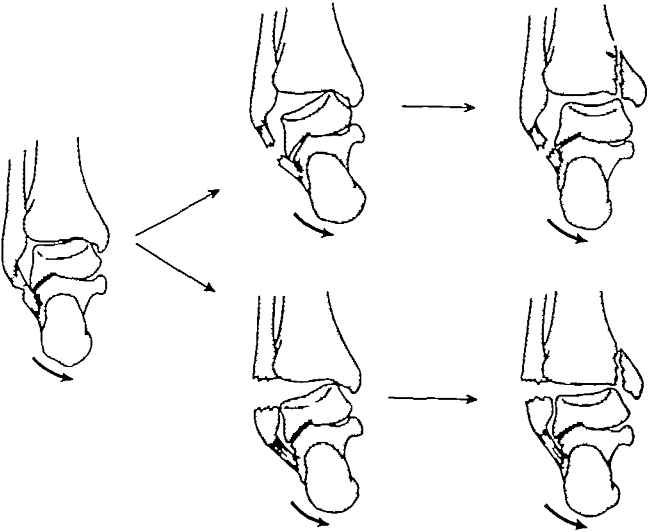

Fig 15. Supination—adduction. (From Quigley T B: J A. M A. 169: 1431 1959)

At the second examination, twenty four hours after injury edema should be minimal, ecchymosis may already have appeared at the periphery of the foam rubber pad (Fig 24) and by gentle palpation and manipulation an accurate analysis of the particular ligaments involved, and their degree of involvement can be made. It is convenient to grade the severity of sprain from I to IV I being the least degree of injury which can be classified as a sprain, and IV complete rupture. Such classification is of help in prognosis a matter of great importance to most athletes and coaches. The majority of sprains fall into grades II and III Experience during the past seventy years at Harvard has established that the commonest ankle injury a grade II sprain of the anterior tibiofibular and fibulotalar ligaments, treated properly with full cooperation from the patient player will be sufficiently healed in 8.2 days to permit full participation in contact sports. It has become equally clear over these seven decades that any prognosis ventured before the second examination twenty four hours after injury is almost certain to be wrong

At this second visit, it can safely be assumed that the sources of bleeding have sealed off and heat, followed by gentle centripedal massage, can be started. Electronic and other complicated sources of heat have little advantage over hot water Diathermy in fact, is contraindicated in joint injuries, since it tends to produce effusion. The psychological effect of a whirlpool bath is much greater than the massage of moving water and bubbles.

Weight bearing is permitted as soon as natural walking is possible. When pain on manipulation and tenderness approach the vanishing point the ankle is taped and the player is put through his paces on

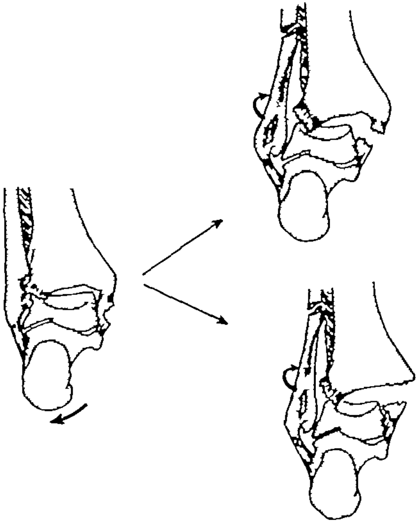

Fig 16. Pronation— external rotation. (From Quigley T B J A M A. 169: 1431 1959)

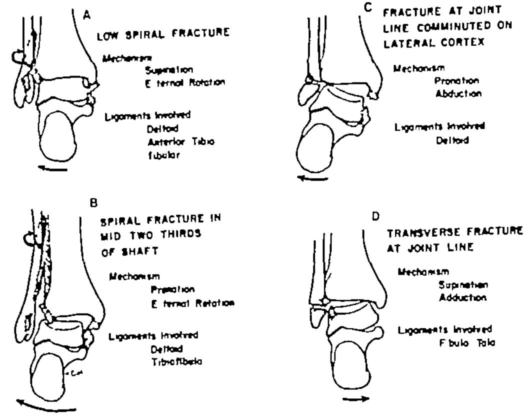

Fig 17 Fibular key to analysis of ankle injuries. (From Quigley T B. J A M A 169: 1431 1959)

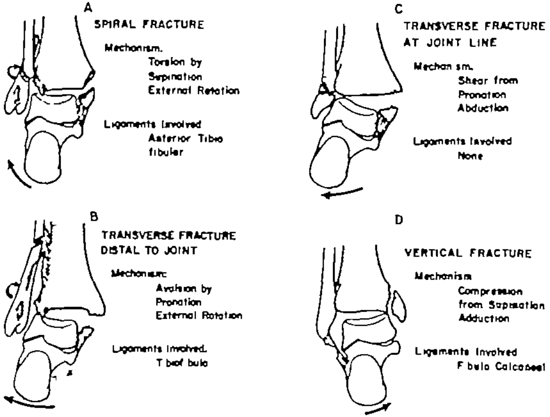

Fig. 18. Medial malleolar key to analysis of ankle injuries (From Quigley T B. J A M A 169: 1431 1959)

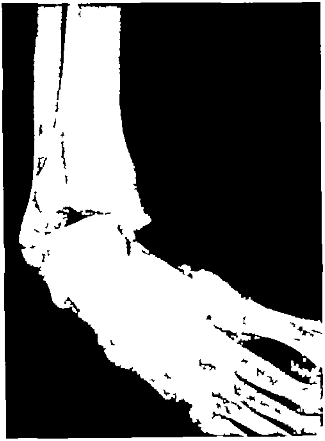

Fig. 19 The effect of old, repeated internal rotation-adduction injuries. Tilting of th talus in relation to the distal articular surface of more than 10 to 15 degrees on forced inversion of the foot demonstrates complete loss of integrity *of the fibulocalcaneal ligament* (*From Bancroft,* F W., and Marble, H. C. In Quigley T B Contusions, Sprains, Strains and Avulsions of Muscles, Tendons, and Ligaments, Philadelphia, 1951 J B. Lippincott Co.)

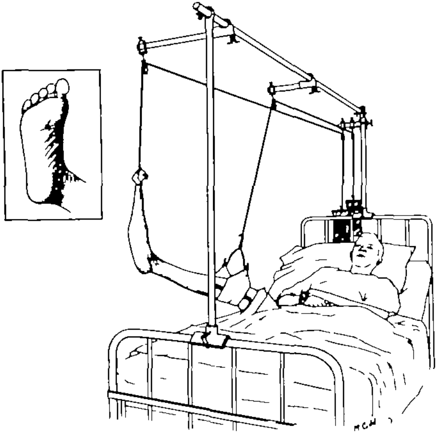

Fig 20. Stockinette suspension for abduction-external rotation fractures of th ankle. The foot and ankle naturally fall into adduction and internal rotation, reversing the mechanism of injury (From Quigley T B. J A. M. A. 169: 1431 1959)

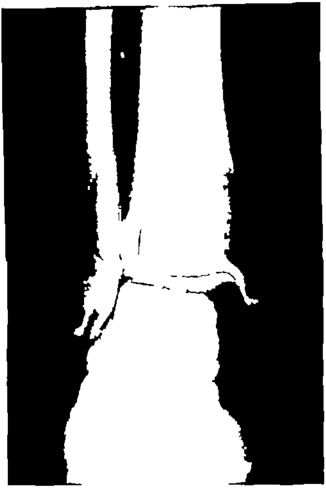

Fig. 21 Abduction-external rotation fracture of the fibula with rupture of the deltoid ligament, sustained in lacrosse. (From Quigley T B J. A. M. A. 169: 1431 1959.)

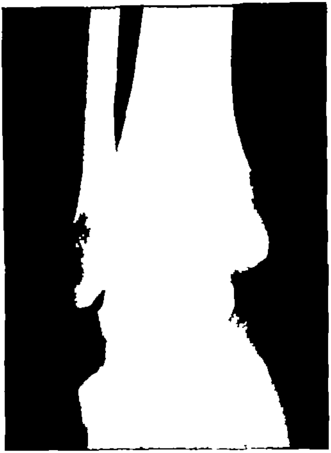

Fig. 22. The fracture and wide joint mortise seen in Fig. 20 has been reduced by suspension overnight in stockinette. The deltoid ligament was explored, was found to be retracted from its distal attachments and rolled on itself and was sutured in proper position. Function for all sports was normal four months after injury. (From Quigley T B J. A. M. A. 169: 1431 1959.)

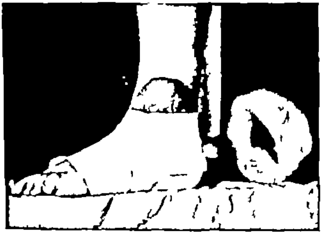

Fig. 23 Foam rubber and elastic bandage compression for anterior tibiofibular and fibular collateral ligament sprain

Fig. 24. Effect of compression on a typical sprain of the anterior tibiofibular ligament of the ankle. Ecchymosis is seen at the periphery of the area of compression. Edema is minimal.

the playing field under the eye of his doctor coach and trainer He returns to full activity only if his performance is flawless. The ankle is protected by adhesive tape with turns around the heel to minimize lateral mobility for at least the next year for every practice session and game. The old adage "once a sprain, always a sprain" has sound basis in the fact that ligament heals with scar which is only very slowly replaced by orderly elastic collagenous tissue and the disorganized fibroblast pattern of scar is always weaker than the tissue it replaces.

There is no justification whatever for the use of procaine in any athletic injury Pain may temporarily be abolished, but performance is usually poor and further damage to the injured structure is almost inevitable Hyaluronidase and hydrocortisone may occasionally have a place when hemorrhage is unusual in degree or sensitivity to pain is high. But it must be remembered that arthrocentesis is no different from arthrotomy from a bacteriological point of view and a locker room is hardly as safe as an operating theater Further no analgesic substance should ever be injected unless it is absolutely clear that pain is much greater than the basic ligament injury usually produces.

Plaster splints are used only for severe or multiple sprains, and then are removed as soon as possible Atrophy of thigh and calf musculature can occur at a remarkable rate and can be corrected only by careful, daily supervised progressive resistance exercise.

SUMMARY

A program of management of ankle injuries sustained in sports, developed over seven decades of experience at Harvard, is presented. Methods of prevention prompt diagnosis, and implementation of treatment for major and minor injuries are described.

REFERENCES

1 Quigley T B., Cox, James, and Murphy Joseph A Protective Wrapping for the Ankle, J A. M. A. 132: 924 1946.

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3. Lauge-Hansen, N: Fractures of the Ankle A M. A. Arch. Surg 64: 488, 1952.

4 Watson-Jones R: Fractures and Joint Injuries, Edinburgh 1943 E. & S Livingstone Ltd., pp 769-772.

5 Quigley T B. A Simple Aid to the Reduction of Abduction-External Rotation Fractures of the Ankle, Am. J Surg. 97: 488, 1959

6. Quigley T B Indications and Contraindications for the Plaster of Paris Walking Boot, Am. J Surg 83 281 1952

MARCUS J STEWART M D
Memphis Tennessee

REHABILITATION IN ATHLETES

Most orthopaedic surgeons are convinced that they know the "essentials of orthopaedic rehabilitation," that they practice good and adequate rehabilitation, and that their approach and methods are completely sufficient. On the contrary few of us know as much as we profess, and few take the time or engender the enthusiasm to convince the patient and to instruct the family and coaches about the importance of this phase of treatment

First, we should follow the basic principle "Rehabilitation begins the day of injury not after the medical and surgical treatment per se has concluded" Begin immediately to maintain regular scheduled activity of all available uninjured parts of the athlete's body Begin muscle setting and active muscle-building exercises of the injured part as soon as possible. For example if you operate on a knee in the morning begin quadriceps setting in the afternoon of the same day then progress to anti gravity straight leg raising as soon as possible, and to flexion and extension of the knee with weight resistance as soon as the limb will tolerate them. *Active exercise* (not early ambulation) is the important feature This accomplishes several purposes (1) maintains good tissue turgor (2) prevents muscle atrophy and adhesions (3) maintains a normal nitrogen balance and (4) preserves a healthy psychological outlook.

For *rehabilitation to be effective* it must meet the following requirements.

1 It must be well organized and have a definite progressive plan.

2. Instructions must be explicit and concise.

3 The doctor must enthusiastically explain the program to the patient in the presence of the family trainer and coach.

4 The surgeon should send a written report of his findings, recommendations, and prognosis to the school and family

Axiom Let us always keep this fact in mind "The *function* of a joint or extremity after correction of injury or insult, will return in direct proportion to the *strength* of the musculature which controlled that limb

Responsibility It is of great advantage if the burden of responsibility for rehabilitation is placed squarely upon the patient (i.e. "put the monkey on the patient's back") A proper mental attitude on the part of both the patient and the doctor is paramount in perfecting a program of rehabilitation. For example following removal of a meniscus from the knee, the patient immediately wants to know how long before he can walk. Time plays no part in the correct answer "When the musculature of the extremity is adequate to control the function of the knee, *then* weight bearing should be allowed and not before" In some instances this may be accomplished in two or three days and in others, two or three weeks it depends upon the patient. I never allow crutch walking by these athletes with soft tissue injuries. If they are kept in bed with a goal of walking depending upon muscle power the incentive to work and build up musculature is greatly stimulated and you will find cooperation at a maximum.

the playing field under the eye of his doctor coach, and trainer He returns to full activity only if his performance is flawless. The ankle is protected by adhesive tape, with turns around the heel to minimize lateral mobility for at least the next year for every practice session and game. The old adage "once a sprain, always a sprain" has sound basis in the fact that ligament heals with scar which is only very slowly replaced by orderly elastic collagenous tissue, and the disorganized fibroblast pattern of scar is always weaker than the tissue it replaces.

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Plaster splints are used only for severe or multiple sprains and then are removed as soon as possible. Atrophy of thigh and calf musculature can occur at a remarkable rate and can be corrected only by careful, daily supervised, progressive resistance exercise.

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SPECIFIC INJURIES

Charley Horse. This all-important subject is often taken too lightly by trainers, coaches, and doctors. When considering a so-called "Charley horse" we should immediately have in mind three phases of this disabling condition

1 *Temporary spasm* in the musculature is the first degree It is the result of a direct blow causing direct stimulation with spasm of a selected portion of the muscle group This will respond immediately to rest.

2. *Hematoma* in the musculature is the second degree, resulting from direct trauma with hemorrhage into the muscle fibers. The injury is one of great importance which receives all too little attention. This is the precursor of myositis ossificans with resulting restriction of muscle function and partial loss of the athlete's effectiveness. Treatment should be specific and immediate ice packs, aspiration (after twenty-four hours) and adequate immobilization followed by muscle rehabilitation.

3 *Rupture* of muscle is the third degree. This lesion demands immediate treatment of a surgical nature.

Thus, the treatment and rehabilitation for a patient with a Charley horse depend first and primarily on an adequate diagnosis of the degree of severity of injury to the musculature involved, with prompt institution of the correct therapy followed by proper muscle rehabilitation.

MUSCLE REHABILITATION

The correct steps in muscle rehabilitation depend primarily on the development of muscle *control power endurance* and *agility*

Proper muscle exercise should be done in a *three cycle count* *One* contract the muscle *two* sustain the contraction for two seconds and *three* relax the muscle completely Only by this method will proper muscle "build-up" be accomplished. If the muscle is held tense and the joint is moved to and fro you merely exhaust the musculature and do not build up its strength and endurance But by relaxation in the cycle you allow nature that split second to make an exchange through the cell membrane of carbon dioxide lactic acid, and waste for fresh oxygen and energy and thus promote genuine recovery and not "waste fatigue"

As the patient's tolerance is extended you increase the amount of weight resistance First, the limb works against gravity and then against 5 pounds, and this is increased gradually until the patient of college age is able to lift 50 pounds fifty times. For the younger high school or teen-age individual, 25 pounds fifty times is adequate. It is not necessary to use quite so much weight for the hamstrings and gastrocnemius groups as for the quadriceps. A similar pattern of muscle building exercise is followed for all extremities, both upper and lower For the back, we have special back exercises (Table 3 Series 1 2, and 3) first to gain control, then movement, and then strength.

Table 3 Instructions in Remedial Exercise (Back)*

Series 1

Breathing exercise (Repeat ten times before each exercise period.) Supine position, knees flexed, arms to the side, deep breathing through the nose with abdominal muscles relaxed.

Supine position

1 Legs straight Static contraction of quadriceps. Hold for count of three. Relax.
2. Knees flexed, hands behind head Contract abdominal muscles and bring head and shoulders just off the table. Hold for count of three. Relax.
3 Knees flexed, hands at side relaxed Pelvic rotation. Tilt pelvis upward, flatten lower back against table. Hold for count of three. Relax.

Prone position

1 *Hands at side* Static contraction of erector spinae and gluteal muscles. Hold for count of three. Relax.
2. Hands at side Static contraction of posterior muscles of legs and hips. (Lifting leg off the table if comfortable alternate.) Hold for count of three. Relax.

NOTE Repeat each exercise five times, three periods each day Increase count by two every second day up to thirty times (Relax between each count.)

Series 2

Breathing exercise (Repeat ten times before each exercise period) Supine position, knees flexed, arms to the side deep breathing through the nose with abdominal muscles relaxed

Supine position

1 One knee flexed Raise opposite leg, knee straight. Alternate right and left
2 Knees flexed, hands behind head Contract abdominal muscles and raise head and shoulders 3 inches off table. Hold for count of three Relax.
3 Knees flexed, hands behind head Deep breathing contracting all muscles of body and lifting head and feet 3 inches off floor Hold for count of three. Relax.
4 Knees flexed, hands at side relaxed: Tilt pelvis upward, flatten lower back against table and gradually slide heels down table straightening knees. Hold back flat and return knees to relaxed position, sliding down one at a time

(Continued on next page)

* From Stewart Exercises, Physical Therapy Department, Campbell Clinic, Memphis, Tenn

Table 7 (Cont'd)

Prone position

1 Hands on buttocks Contract erector spinae and gluteal muscles raising head and shoulders off the table hand sliding down the back of thighs

2 Hands at sides relaxed Alternate straight leg raise

3 Hands at sides Contract erector spinae and gluteal muscles, raising head and shoulders and reach down side of leg Return to starting position Relax Alternate sides.

NOTE: Repeat each exercise five times, three periods a day Increase count by five every second day up to fifty times (Relax between each count)

Series 3

Breathing exercise (Repeat ten times before each exercise period) Supine position, knees flexed arms to the side deep breathing through the nose with abdominal muscles relaxed.

Supine position

1 Hands behind head: Rise to sitting position lie back down. Raise legs to vertical position with knees straight let down. Relax

2. Legs straight and astride arms folded across chest Return position of feet and lower limbs roll, touching floor to right and then left with nose

Prone position

1 Legs astride ten-pound sandbag at base of neck hands behind back Raise head and chest alternate bending to right left. Return to rest position.

Side-lying position

1 Arms folded to front: Lift torso upward Relax Repeat on opposite side

Standing position

1 Legs astride hands over head Touch floor in front of feet, then between feet to the rear and again in front Fix pelvis and slowly unroll to erect position

2. Legs astride arms to side Alternate touching right hand to left foot and left hand to right foot

NOTE Repeat each exercise ten times three periods a day Increase count by five every second day up to fifty times (Relax between each count)

Specific Members

Neck and Back. Rehabilitation of neck dorsal and lumbar spine areas is accomplished not by excessive bending but by repeated muscle-setting or tensing exercises We divide this into three phases of rehabilitation

Series 1 remedial back exercises, for example are designed primarily for the muscle setting of all musculature from the head to the feet With the patient lying in a supine position muscle setting is done for the entire front of the body including neck chest abdomen, and extremities In the prone position the patient raises his head and shoulder 1 cm then his lower extremities, alternating right and left without bending the knee and at no time using his arms for assistance Motion is not the objective the patient is never required to raise his head or feet more than 1 cm from the floor The count on each of these maneuvers is begun at five and increased with repetition to thirty five or forty for each exercise period.

Series 2 remedial back exercises are designed to develop motion after the patient has gained the muscle control of *Series 1* *Series 3* back exercises are designed to build muscle power and are used primarily with athletes, soldiers, and industrial workers.

Arm and Shoulder Many excellent athletes have had shoulders and arms ruined for competitive sports by a trainer or coach attempting to "work out a kink" when actually he was dealing with a muscular or tendinous tear Adequate diagnosis is imperative. Are you dealing with a tear of the rotator cuff of the shoulder or some similar injury which demands rest for healing? Rehabilitation after healing here as in the back, follows the pattern of (1) muscle setting (or control) (2) development of motion and (3) development of power

Elbow Wrist, and Fingers. Elbow and finger joints can well be considered together They are tense tight joints, with very little fluid capacity surrounded by thick, strong fibrous tissue and when this tissue is stretched or torn it merely produces hemorrhage and more scar tissue. *Passive motion is always contraindicated in these joints* It is well to note that passive motion is of little or no advantage in the rehabilitation of any joint. The only extrinsic power which should ever be used to rehabilitate an elbow or hand is the musculature of the extremity involved No passive force or assistance from the physical therapist trainer doctor or the patient's opposite hand should ever be employed. Certainly the hanging of weights such as irons or sandbags on the arm to stretch out the elbow is deplorable.

Hip. Rehabilitation of the hips depends primarily on the establishment of adequate musculature in the gluteal and quadriceps groups. The gluteus maximus is the most important, but the medius and minimus are the most neglected of the muscles about the hip and they demand specific remedial muscle building exercise

Knee. Establishment of function in the knee following correction of the many injuries which befall this most frequently injured joint in athletics demands meticulous attention to intricate details. One

must keep in mind the many vulnerable structures in the knee. The outstanding work of Brantigan and Voshell in describing the anatomy of the knee has been well culminated in the monumental clinical work accomplished by O'Donoghue.

Nowhere is it more graphically illustrated than in the knee that there is always marked reflex muscle atrophy and weakness following any of the various injuries to the joint, even traumatic synovitis. It is obvious from comparison with the opposite limb how marked is the immediate muscle atrophy After restoration of the anatomy of the knee, whether it be by conservative or surgical means, rehabilitation becomes paramount for the restoration of the individual to competitive athletics. Again, we must follow the plan of muscle setting or control, muscle-building exercises, and motion developing until restoration is complete. It is not sufficient just to restore the quadriceps for proper function of the knee building up of the hamstrings and the gastrocnemius group by weight-resisting exercises is also extremely important. Following correction of severe injuries and rehabilitation, it is important to continue specific, active, weight-resistant exercise for several months, even though the patient has returned to competitive sports.

Ankle and Foot. Here, as in the shoulder adequate diagnosis is often sadly neglected. Manual examination of an ankle is seldom adequate to establish the correct diagnosis as to the extent of soft tissue injury If severe ligamentous tear is suspected, *one should resort to examination under anesthesia* either local or general. X-ray examination is always *demanded in these moderate to severe athletic injuries.* One should keep in mind not only fractures of the bones but also osteochondral fractures, which are often obscure in the roentgenogram. Strain roentgenograms for various ligamentous structures of the joints are often the only means of establishing a correct diagnosis.

RETURN TO ACTIVITY

In the process of rehabilitation, the doctor is faced with that all-important decision which has been so well discussed by Dr Robert Brashear "When can the patient return to the game or to practice?" If you are to be fair to the athlete, to the trainer to the coach, and to the patient's parents, you must assume a considerable amount of responsibility You should determine when the patient can return to active competitive sports. Anyone knows that when the patient is normal he can participate you must make the decision as to when he has approached normalcy enough to return to his previous activities. Remember that we are a great nation of week-end athletes and that most athletes are not professionals.

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CLOSING COMMENTS

I know you have all profited, as I have, from the splendid presentations we have just heard. Obviously it has been impossible to blanket the whole field of injuries to athletes but we have made an effort to present certain definite facets of the problem in order that you may apply the same precepts to other conditions which you will encounter Let me emphasize once again that one of the major functions of the orthopaedist is educational. While a great majority of the serious skeletal injuries to athletes should be treated by the orthopaedist, these injuries are the minority Of greater number are the so-called minor injuries—minor at least in the fact that they are so often inadequately treated! At the present time one of the major problems is in the smaller schools. We are making a special effort in my home state to filter some of the training down to the smaller high schools and I know of similar efforts in many other parts of the country

In these particular programs the orthopaedist must take the lead. He must not take the attitude that every sprained ankle must be treated by the specialist On the other hand he must not take the attitude that he should not invite consultation in the case of serious injury The orthopaedist must keep himself on call to attend meetings of medical societies to aid in instructing his colleagues. He should cooperate in the effort to improve conditioning and training by informing himself as to these problems. He should make it seem important to the home physician to cooperate with the school authorities toward these desirable ends.

There are many facets to this problem, not all of them visible. Someone in the audience may know of the experience in California where the committee had arranged to have a doctor present at every scrimmage session of their local high school. This worth-while project received a very serious backset as the result of a lawsuit against one of the physicians because the parents did not feel he had done the best he could do under an emergency situation The realm or responsibility under such a condition must be clearly defined Possibly in connection with athletic insurance some statement should be signed by the parents, authorizing examination of these boys and in emergency situations permitting specific treatment. These, however are details which certainly can be solved with cooperative effort. The fact remains that we as orthopaedists must put our weight behind the movement to prevent injuries, and above all, to obtain prompt definitive and adequate care for the unfortunate athlete who does receive an injury

PART TWO

THE HAND

ARTHUR H STEIN, JR,
St Louis M

ANATOMY OF THE HAND

A detailed knowledge of the gross anatomy of the hand is an absolute prerequisite for the surgeon who undertakes the repair or reconstruction necessitated by injuries to the human hand. Periodic review is necessary to keep the surgeon alert to the many fine and important anatomical structures that he encounters when operating in the hand. The illustrations included here represent photographs taken during the actual dissection of a freshly amputated specimen.

SURFACE ANATOMY

The skin of the hand has many characteristics which are specific to this area of the body. The palmar skin is thick, relatively inelastic, and is devoid of hair. The skin of the finger pads is thrown up into a pattern of ridges and sulci. Along the surface of these ridges many large sweat glands open to the surface. These glands are innervated by the sympathetic nerves and cease to function when the sympathetic nerve fibers to the hand are sectioned. The absence of sweating may be recognized within thirty to sixty minutes after section of the peripheral nerves, any place in the upper extremity distal to the point where the sympathetic fibers join the main nerve trunks. The characteristic ridges of the finger tips gradually become much less prominent after denervation.

The palmar surface of the hand is richly supplied with sensory endings. Free nerve endings and Meissner's and Pacinian corpuscles are abundant in the palmar surface of the hand and the fingers. The flexion creases in the palm and at the interphalangeal and metacarpophalangeal joints are relatively constant in the normal hand. The adductior the mid palmar crease the distal palmar and all of the flexion creases of the fing thumb end at the mid lateral portion of tl and each finger. The absence of these flexion on the mid lateral side of the digits is an in landmark and indicates the site of the tr lateral approach to the finger.

The skin over the dorsum of the hand an is considerably more elastic, and flexion cre less pronounced. There are few sweat gland abundance of hair over the dorsum of the h the dorsal surface of the fingers. The majoi creases overlie the proximal interphalangea These flexion creases also end at the mi side of the finger.

On the dorsal surface the superficial ven tem is extremely prominent. These veins r the principal venous drainage of the hanc veins from the palm of the hand and the surface of the fingers curve around the late gins of the fingers to reach the dorsal surfa each finger there is a dorsal digital rete wh over the proximal portion of the proximal of each finger in the dorsal digital arch. Th digital arch drains into the dorsal metacarp which with many intercommunicating veu the dorsal carpal rete. From this point dra into the basilic and the cephalic veins. The vein takes its origin from the veins on the do face of the hand just proximal to the radia process. The basilic vein has its origin on tl aspect of the dorsal surface of the wrist ju imal to the head of the ulna.

ARTHUR H STEIN JR M D
St Louis Missouri

ANATOMY OF THE HAND

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SURFACE ANATOMY

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The skin over the dorsum of the hand and fingers is considerably more elastic, and flexion creases are less pronounced. There are few sweat glands but an abundance of hair over the dorsum of the hand and the dorsal surface of the fingers. The major flexion creases overlie the proximal interphalangeal joints. These flexion creases also end at the mid lateral side of the finger.

On the dorsal surface the superficial venous system is extremely prominent. These veins represent the principal venous drainage of the hand. Small veins from the palm of the hand and the palmar surface of the fingers curve around the lateral margins of the fingers to reach the dorsal surface. Over each finger there is a dorsal digital rete which ends over the proximal portion of the proximal phalanx of each finger in the dorsal digital arch. The dorsal digital arch drains into the dorsal metacarpal veins which, with many intercommunicating veins, form the dorsal carpal rete. From this point drainage is into the basilic and the cephalic veins. The cephalic vein takes its origin from the veins on the dorsal surface of the hand just proximal to the radial styloid process. The basilic vein has its origin on the ulnar aspect of the dorsal surface of the wrist just proximal to the head of the ulna.

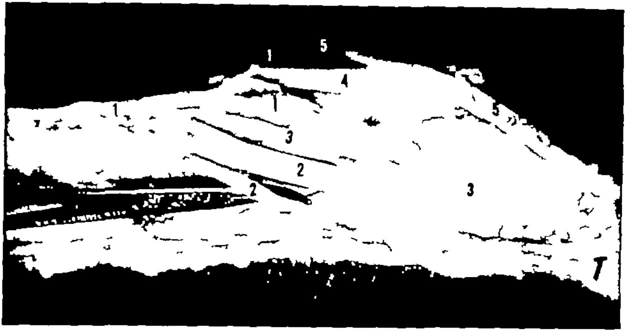

Fig. 25. Dorsolateral aspect of th wrist showing the first compartment on the dorsum of the wrist. The large T indicates the base of the thumb. 1 Superficial radial nerve and two of its branches. 2, Abductor pollicis longus tendons. Note the two separate components. 3 Extensor pollicis brevis tendon. 4 Extensor carpi radialis longus tendon. 5, Extensor pollicis longus tendon.

ANATOMY OF THE DORSUM OF THE WRIST AND HAND

The key to understanding the anatomy of the dorsum of the wrist and hand is a knowledge of the six major compartments through which the tendons pass from the forearm into the hand. These compartments are formed in part by the bony prominences of the dorsal surface of the distal radius and ulna. The antibrachial fascia is thickened to form the dorsal carpal ligament and completes the compartment formation where it attaches to the bony prominences. The first compartment lies in close approximation to the radial styloid process on the dorsoradial aspect of the wrist (Fig 25). Through this compartment pass two tendons. The larger and more volar tendon is the abductor pollicis longus. The smaller tendon lying dorsally is the extensor pollicis brevis. In some instances, a small fibrocartilaginous septum may separate the abductor pollicis longus and the extensor pollicis brevis. In 68 per cent of instances the abductor pollicis longus is divided into two or more components, with its insertion into the base of the first metacarpal, the trapezium, and the fascia overlying the thenar muscle group. The extensor pollicis brevis is absent in 1 to 2 per cent of the cases.[4] The normal insertion of the extensor pollicis brevis is into the base of the proximal phalanx and the extensor hood of the thumb. The dorsal interosseous nerve innervates both of these muscles.

Two tendons, the extensor carpi radialis longus and the extensor carpi radialis brevis, occupy the second compartment on the dorsum of the wrist (Fig 26). The extensor carpi radialis longus inserts into the base of the dorsal surface of the second metacarpal while the extensor carpi radialis brevis has its insertion into the dorsal surface at the base of the third metacarpal. Both muscles are supplied by branches of the radial nerve prior to its division into the superficial and deep branches, or proximal to the penetration of the deep motor branch into the supinator muscle.

The third compartment contains a single tendon the extensor pollicis longus (Fig 26). This tendon, after passing Lister's tubercle on the dorsal surface of the radius, follows an oblique course, superficial to the extensor carpi radialis brevis and longus, to the radial side of the hand where it inserts into the extensor hood and the dorsum of the distal phalanx of the thumb. This muscle is supplied by a branch of the dorsal interosseous nerve.

The four divisions of the extensor digitorum communis and its companion tendon, the extensor in

s proprius, pass through the fourth compart nt (Fig 26) The insertion of these two tendons principally into the extensor hood for each of the gers. Its more detailed insertion will be discussed der the subject of the extensor hood of the finger er the metacarpal necks the extensor tendons to index and ring fingers give off a fibrous band to extensor tendon of the long finger known as the nctura tendinum. The extensor indicis proprius s to the ulnar side of the common extensor tendon the index finger The nerve supply to these two uscles is the dorsal interosseous nerve.

The fifth compartment on the dorsal surface of e wrist contains the extensor digiti quinti (Fig

Fig 26. Dorsal aspect of the wrist showing five of the six compartments 1 Extensor carpi ulnaris tendon. 2, Extensor digiti quinti tendon. Note the two separate slips of tendon 3 The various components of the extensor digitorum communis tendon. 4 Extensor indicis proprius tendon 5, Extensor carpi radialis brevis tendon. 6, Extensor carpi radialis longus tendon. 7 Extensor pollicis longus tendon.

26) This tendon is always on the ulnar side of the common extensor tendon to the little finger Characteristically it is divided into two rather distinct slips. The nerve supply is from the dorsal interosseous nerve. The insertion of the extensor digiti quinti is into the extensor hood of the little finger

In the sixth compartment is the extensor carpi ulnaris which after passing the ulnar styloid process goes to its insertion at the base of the fifth metacarpal (Fig 26) This muscle is supplied by a branch of the dorsal interosseous nerve.

Bunnell[3] studying the excursion of tendons of the wrist and hand found that the wrist extensors, which would include the extensor carpi radialis longus and brevis and the extensor carpi ulnaris had a total excursion of approximately 1¼ inches. The finger extensors have an excursion of approximately 2 inches. The extensor pollicis longus has the greatest excursion of the extensor group, and this has been measured to be as much as 2¼ inches.

There are two potential spaces on the dorsal surface of the hand which may be of importance when dealing with infection. The first of these spaces is the dorsal subcutaneous space. The dorsal subcutaneous space of the hand extends from the level of the wrist joint to the level of the metacarpophalangeal joints. It is superficial to the tendons and does not communicate with the palm of the hand. The second of these spaces is the dorsal subaponeurotic space which lies deep to the extensor tendons as they cross the dorsal surface of the hand. This space extends from the level of the wrist to within approximately 1 3 cm. of the metacarpophalangeal joints. It is bounded laterally by the second and fifth metacarpals and does not communicate with the palm of the hand.[4]

ANATOMY OF THE VOLAR SURFACE OF THE WRIST

There are three flexors of the wrist joint. On the radial side is the flexor carpi radialis which has its insertion into the base of the second metacarpal. The excursion of this tendon is approximately 1¼ inches. The nerve supply is from the median nerve. The centrally located wrist flexor tendon is the palmaris longus which has its insertion into the palmar aponeurosis. In approximately 10 to 12 per cent of individuals this tendon is absent.[4] The nerve supply of this muscle is from the median nerve. On the ulnar side is the flexor carpi ulnaris which inserts into the pisiform, the pisohamate

ligament, and as far distally as the hook of the hamate. The excursion of this tendon is approximately 1¼ inches. Its nerve supply is from the ulnar nerve.

In the central portion of the volar aspect of the wrist (Fig 27) there is a distinct anatomical compartment known as the volar carpal canal. The floor of the volar carpal canal is composed of the ligaments joining the volar surface of the carpal bones. The radial boundary is the radial carpal eminence which is composed of the tuberosity of the carpal scaphoid, the greater multangular and the *ligaments which connect these two bones.* The ulnar carpal eminence is composed of the pisiform the hook of the hamate and the pisohamate ligament. Thus, there is formed a groove on the volar aspect of the wrist which is converted into a tunnel by the transverse carpal ligament (Fig 28) The transverse carpal ligament attaches to the radial and ulnar carpal eminences. This ligament is tough thick, and unyielding

Ten major structures pass through the volar carpal canal. The most superficial of these is the median nerve. Lying just deep to the median nerve are the four flexor sublimus tendons. These tendons are arranged in a rather characteristic fashion with the tendon to the long finger and the ring finger being the most superficial. Deep to the sublimus tendons are the four flexor profundus tendons to each of the fingers. The tenth structure to pass through the volar carpal canal is the flexor pollicis longus tendon It lies on the floor of the radial side of the carpal canal and passes to its insertion at the base of the distal phalanx of the thumb

ANATOMY OF THE PALM OF THE HAND

Palmar Aponeurosis. Just deep to the palmar skin is the palmar aponeurosis, which is a complicated sheath of interlacing bands of fibrous tissue (Fig 29) There are four projections of the palmar aponeurosis distally one into each of the four fingers. This projection extends at least as far distally as the proximal interphalangeal joint. There are, in the distal third of the palm, eight distinct arches from the palmar aponeurosis which pass deep into the palm of the hand The four major arches enclose the flexor tendons. The most important of the four major arches forms a complete membrane and attaches along the shaft of the third metacarpal This septum divides the mid palmar and the thenar spaces in the palm of the hand. The four minor

Fig. 29. Palmar surface of the hand showing the palmar aponeurosis. 1 Insertion of the tendon of the palmaris longus. 2, Longitudinal fibers of the palmar poneurosis. 3, Transverse fibers f the palmar aponeurosis. 4 Extension of the palmar aponeurosis into the volar aspect of th index finger 5, Proper digital nerves.

arches cover the vessels and nerves and are known as the lumbrical canals. The proximal end of the palmar aponeurosis is the site of insertion of the palmaris longus tendon. In addition there are projections of the palmar aponeurosis toward the surface of the hand these are particularly prominent where there are major flexion creases in the palm of the hand.

Blood Supply Directly under the palmar aponeurosis is the superficial palmar arch of the hand (Fig 30) This arch is made up of two component parts the major portion being from the superficial branch of the ulnar artery and the minor portion being from the superficial branch of the radial artery The superficial palmar arch lies superficial to the major nerve structures in the palm of the hand. The arch gives off four relatively constant branches. There are three common digital arteries,

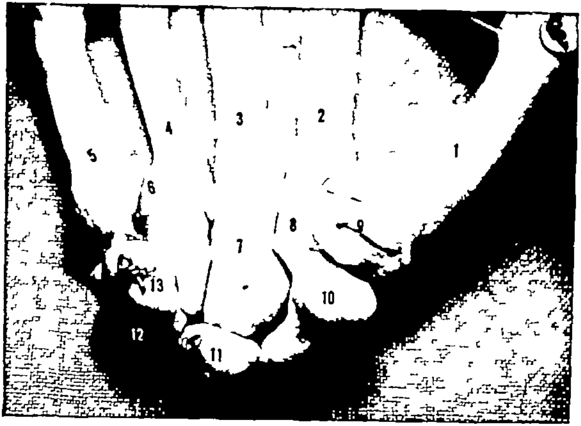

Fig. 27 Volar aspect of the carpus and metacarpus. 1, First metacarpal. 2, Second metacarpal. 3, Third metacarpal. 4 Fourth metacarpal 5, Fifth metacarpal. 6, Hook of the hamate. 7 Capitate. 8, Lesser multangular 9 Greater multangular 10, Tuberosity of the carpal scaphoid. 11 Lunate. 12, Triquetrum 13 Pisiform.

Fig 28. Volar aspect of the wrist illustrating the relation of the median and ulnar nerves to the transverse carpal ligament. The palmar aponeurosis has been removed. 1 Median nerve 2 Ulnar nerve 3, Transverse carpal ligament. Note the broad expanse of this ligament. 4, Abductor pollicis brevis muscle. 5, Tendon of the flexor carpi ulnaris 6, Flexor sublimis tendon to the ring finger 7 Common digital branch from the superficial portion of the ulnar nerve. 8, Proper digital branch of the ulnar nerve. This branch supplies the ulnar side of the little finger 9 Abductor digiti quinti muscle. 10, Tendon of the flexor carpi radialis

major components the deep component which is entirely motor and the superficial portion which is principally sensory in function The superficial branch of the ulnar nerve divides into a single common digital nerve which courses deep to the palmar aponeurosis and opposite the fourth metacarpal neck, divides into two proper digital branches for the radial side of the little finger and the ulnar side of the ring finger The other major branch of the superficial portion of the ulnar nerve is a proper digital branch for the ulnar side of the little finger A small branch is also given off to the palmaris brevis muscle (Figs. 28 and 32.)

The deep branch of the ulnar nerve (Fig 33) is entirely motor and supplies all the interosseus muscles, the hypothenar muscles the lumbrical muscles to the little and ring fingers the adductor pollicis and the deep head of the flexor pollicis brevis. The last muscle on the radial side of the hand to be innervated by the ulnar nerve is the first dorsal interosseus muscle The motor branch penetrates deep into the palm just distal to the pisiform. It

Fig 31 The palmar aponeurosis the transverse carpal ligament, and the superficial palmar arch have been removed to illustrat the six branches of th median nerve in the palm. 1 Median nerve. 2, Recurrent motor branch to the abductor pollicis brevis, the opponens pollicis, and the superficial head of the flexor pollicis brevis. 3 The two proper digital branches to the two sides of the thumb. 4 Proper digital branch to th radial side of the index finge 5, The two common digital nerves 6, The four proper digital nerves after division of the two common digital branches These supply the ulna side of the index finger both sides of the long finger and the radial side of the ring finger 7 Common digital branch of the ulnar nerv 8, Proper digital branch of the ulna nerv 9 Flexor sublimis group of tendons. 10, Abductor pollicis brevis muscle. 11 Prominence of the pisiform.

Fig. 32. Volar aspect of the wrist to show the major divisions of the ulnar nerve The olar carpal ligament has been removed and the ulnar nerve lifted from its bed. 1 Median nerve. 2, Expanse of the transverse carpal ligament. 3 Flexor carpi radialis tendon. 4 Flexor sublimis group of tendons. 5, Ulnar nerve. 6, Deep (motor) branch of the ulnar nerve in the hand. 7 Common digital nerve of th superficial division of the ulnar nerv This branch divides into two proper digital nerves to supply adjacent sides of the ring finger and the little finger 8, Proper digital branch from the superficial portion of the ulnar nerve. This supplies the ulnar side of the little finger 9, Tendon of the flexor carpi ulnaris. 10, Abductor digiti quinti muscle. 11 Abd ctor pollicis brevis muscle

which at the level of the metacarpal necks divide to give six proper digital arteries. There is a single volar digital artery to the ulnar side of the little finger. The superficial palmar arch is, therefore, the major arterial supply to the little finger, the ring finger, the long finger, and the ulnar side of the index finger. At the level where the three common digital arteries divide into proper digital arteries, small perforating branches are given off and penetrate deep into the palm of the hand to anastomose with the volar metacarpal arteries which arise from the deep palmar arch.

Fig. 30. The palmar aponeurosis has been removed to reveal the superficial palmar arch. Note that the vessels are superficial to the major nerves. 1, Median nerve. 2, Transverse carpal ligament. 3, Prominence of the pisiform showing the volar carpal ligament in place. This ligament is continuous with the transverse carpal ligament after arching over the ulnar nerve. 4, Ulnar nerve. 5, Proper digital nerve to the ulnar side of the little finger. 6, Common digital nerve from the superficial portion of the ulnar nerve. 7, Superficial branch of the ulnar artery. 8, Superficial palmar arch. 9, Superficial branch of the radial artery. 10, Common digital arteries. 11, Proper digital artery to the ulnar side of the little finger. 12, Abductor pollicis brevis muscle. 13, Abductor digiti quinti muscle. 14, Proper digital nerve to the radial side of the index finger.

The deep palmar arch also has two components. The major component is the deep branch of the radial artery after it passes between the two heads of the first dorsal interosseus muscle. The smaller component is a deep branch from the ulnar artery. The deep palmar arch is smaller than the superficial palmar arch, lies deep to all the flexor tendons, and is approximately 1 inch more proximal than the superficial arch. *The major branches of the deep palmar arch* are four in number. The first of these is the princeps pollicis artery, which usually divides to give two proper digital arteries to the adjacent sides of the thumb. A radial volar digital artery of considerable size is given off by the deep arch to supply the radial side of the index finger. Three small volar metacarpal arteries course distally to anastomose with the perforating branches from the superficial arch. In addition there are small recurrent carpal arteries which course proximally to supply the carpal area.

Nerves of the Palm. The nerve supply to the palmar surface of the hand is from the median and ulnar nerves. The median nerve, after passing through the volar carpal canal, divides into six major branches (Fig. 31). The first branch given off to the radial side is the recurrent motor branch which supplies the abductor pollicis brevis, the *opponens pollicis, and the superficial head of the flexor* pollicis brevis. The remaining five branches of the median nerve are essentially sensory in function. There are three proper digital nerves, two of which supply the thumb, and one of which supplies sensation to the radial side of the index finger. The remaining two branches of the median nerve are common digital nerves which divide into four proper digital nerves opposite the neck of the metacarpals. These four proper digital nerves then supply the ulnar side of the index finger, both sides of the long finger, and the radial side of the ring finger (Fig. 31). In addition a small motor branch arises from the proper digital nerve to the index finger to supply the first lumbrical muscle. The second lumbrical receives a small branch from the first common digital nerve.

The ulnar nerve does not pass deep to the transverse carpal ligament. Instead it courses around the *radial aspect* of the pisiform lying on the transverse carpal ligament. (Figs. 28 and 30.) It is covered by a small slip of fascia, which in the past has been known as the volar carpal ligament. As the ulnar nerve *passes the pisiform*, it divides into two

major components the deep component which is entirely motor and the superficial portion which is principally sensory in function The superficial branch of the ulnar nerve divides into a single common digital nerve which courses deep to the palmar aponeurosis and opposite the fourth metacarpal neck, divides into two proper digital branches for the radial side of the little finger and the ulnar side of the ring finger The other major branch of the superficial portion of the ulnar nerve is a proper digital branch for the ulnar side of the little finger A small branch is also given off to the palmaris brevis muscle (Figs. 28 and 32)

The deep branch of the ulnar nerve (Fig 33) is entirely motor and supplies all the interosseus muscles, the hypothenar muscles the lumbrical muscles to the little and ring fingers, the adductor pollicis, and the deep head of the flexor pollicis brevis. The last muscle on the radial side of the hand to be innervated by the ulnar nerve is the first dorsal interosseus muscle The motor branch penetrates deep into the palm just distal to the pisiform. It

Fig. 31 The palmar aponeurosis, the transverse carpal ligament, and the superficial palmar arch have been removed to illustrate the six branches of the median nerve in the palm. 1 Median nerve. 2, Recurrent motor branch to the abductor pollicis brevis, the opponens pollicis, and the superficial head of the flexor pollicis brevis. 3, The two proper digital branches to the two sides of the thumb. 4, Proper digital branch to the radial side of the index finger 5, The two common digital nerves. 6, The four proper digital nerves after division of the two common digital branches. These supply the ulnar side of the index finger both sides of the long finger and the radial side of the ring finger 7 Common digital branch of the ulnar nerve. 8, Proper digital branch of the ulnar nerve 9, Flexor sublimis group of tendons. 10, Abductor pollicis brevis muscle. 11 Prominence of the pisiform

Fig. 32. Volar aspect of the wrist to show the major divisions of the ulnar nerve The volar carpal ligament has been removed and the ulnar nerve lifted from its bed. 1 Median nerve. 2, Expanse of the transverse carpal ligament. 3, Flexor carpi radialis tendon. 4, Flexor sublimus group of tendons. 5, Ulnar nerve 6, Deep (motor) branch of the ulnar nerve in the hand. 7 Common digital nerve of the superficial division of the ulnar nerve. This branch divides into two proper digital nerves to supply adjacent sides of the ring finger and the little finger 8, Proper digital branch from the superficial portion of the ulnar nerve This supplies the ulnar side of the little finger 9 Tendon of the flexor carpi ulnaris. 10, Abductor digiti quinti muscle 11 Abductor pollicis brevis muscle

lies on the proximal portion of the volar interosseus muscles and the proximal shaft of the metacarpals. It closely parallels the deep palmar arch in the central portion of the palm but is slightly proximal to the vascular arch.

The radial nerve to the hand has no motor components. It supplies sensation as far ulnarward as the midline of the dorsum of the long finger and distally along the dorsum of the index and long fingers as far as the proximal interphalangeal joint. The dorsal surface of the distal phalanx of the thumb may also have its main sensory innervation from the radial nerve. (Fig 34)

The proper digital nerves to each finger are the main sensory supplies to the digit (Fig 35) As the digital nerve passes distally along the finger it lies on the volar side of the proper digital artery There

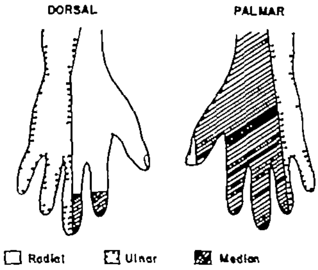

Fig 34 Schematic drawing showing the common sensory distributions on the palmar and dorsal surfaces of the hand.

Fig 35 Palmar side of the hand to illustrate the deep branch of the ulnar nerve The palmar aponeurosis, superficial vessels nerves, and all the long flexor tendons have been removed 1 Ulnar nerve 2, Superficial branch (proper digital nerve 3 Deep branch of the ulnar nerve showing some of its divisions 4 Deep palmar arch 5, Transverse head of the adductor pollicis muscle 6, Flexor pollicis brevis muscle 7 First dorsal interosseus muscle. 8, Abductor pollicis brevis muscle. 9 Volar carpal canal. The transverse carpal ligament has been removed.

by the relationship between the major artery and nerve has been reversed in comparison to the palm of the hand. Opposite the distal portion of the proximal phalanx of each finger the proper digital nerve gives off branches to the dorsal surface of the finger There is usually one major branch and many smaller branches as the nerve courses distally Sensation to the finger therefore, over the middle and distal phalanges of the dorsal surface is supplied by the proper digital nerve of the individual finger

Tendons. There are two long flexor tendons to each of the four fingers (Fig 36) The most superficial of the group is the flexor sublimis tendon. The sublimis tendons have their insertion at the base of the middle phalanx of each of the fingers. Over the middle of the proximal phalanx each of the sublimis tendons divides into two slips, and through this hiatus in the tendon passes the flexor profundus tendon. The profundus tendon then continues distally down the volar aspect of the finger to its site of insertion at the base of the distal phalanx. In addition to the insertion into the middle and distal phalanges each of these tendons has a supplementary attachment through the vincula. Each tendon has a long and a short vinculum. The vinculum is a small, mesentery like structure which passes from the floor of the osteofibrous canal to the tendon and usually it will transmit a small blood vessel which is important in nourishment of the tendon. The excursion of the sublimis tendon in its full extent at the level of the wrist is approximately

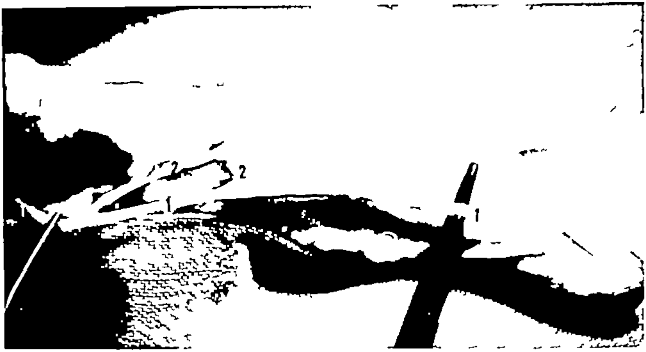

Fig. 35. Lateral view of the index finger to illustrate the proper digital nerve 1 Proper digital nerve 2, Dorsal branches of the proper digital nerve These branches supply the dorsal surface of the finger distal to the proximal interphalangeal joint.

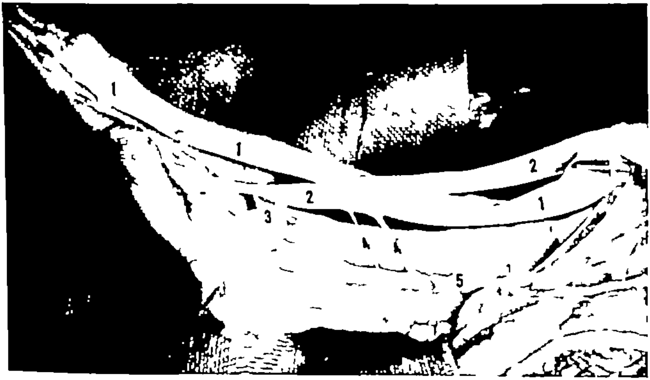

Fig. 36. Lateral view of the index finger to illustrate the long flexor tendons and their vincula 1 Flexor profundus tendon 2, One of the two slips of the flexor sublimis tendon. 3, Vinculum breve 4 Vincula longa 5, Cut edge of flexor tendon sheath

lies on the proximal portion of the volar inter osseus muscles and the proximal shaft of the meta carpals. It closely parallels the deep palmar arch in the central portion of the palm but is slightly proximal to the vascular arch.

The radial nerve to the hand has no motor components. It supplies sensation as far ulnarward as the midline of the dorsum of the long finger and distally along the dorsum of the index and long *fingers as far as the proximal interphalangeal* joint. The dorsal surface of the distal phalanx of the thumb may also have its main sensory innervation from the radial nerve. (Fig 34)

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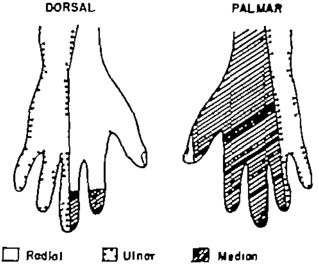

Fig. 34. Schematic drawing showing the common sensory *distributions on the palmar nd dorsal surfaces of the* hand.

Fig 33. Palmar side of the hand to illustrate the deep branch of the ulnar nerve Th palmar aponeurosis, superficial arch, nerves, and ll the long flexor tendons have been removed 1 Ulnar nerv 2, Superficial branch (prope digital nerv) 3 Deep branch of the ulna nerv showing some of ts divisions. 4, Deep palma rch. 5, Transverse head of the adductor pollicis muscle 6, Flexor pollicis brevis muscle 7 First dorsal interosseus muscle. 8, Abductor pollicis brevis muscle. 9, Vola carpal canal. The trans erse carpal ligament has been removed

by the relationship between the major artery and nerve has been reversed in comparison to the palm of the hand. Opposite the distal portion of the proximal phalanx of each finger the proper digital nerve gives off branches to the dorsal surface of the finger There is usually one major branch and many smaller branches as the nerve courses distally Sensation to the finger therefore, over the middle and distal phalanges of the dorsal surface is supplied by the proper digital nerve of the individual finger

Tendons. There are two long flexor tendons to each of the four fingers (Fig 36) The most superficial of the group is the flexor sublimis tendon *The sublimis tendons* have their insertion at the base of the middle phalanx of each of the fingers. Over the middle of the proximal phalanx each of the sublimis tendons divides into two slips, and through this hiatus in the tendon passes the flexor profundus tendon. The profundus tendon then continues distally down the volar aspect of the finger to its site of insertion at the base of the distal phalanx. In addition to the insertion into the middle and distal phalanges each of these tendons has a supplementary attachment through the vincula. Each tendon has a long and a short vinculum. The vinculum is a small, mesentery like structure which passes from the floor of the osteofibrous canal to the tendon and usually it will transmit a small blood vessel which is important in nourishment of the tendon.[1] The excursion of the sublimis tendon in its full extent at the level of the wrist is approximately

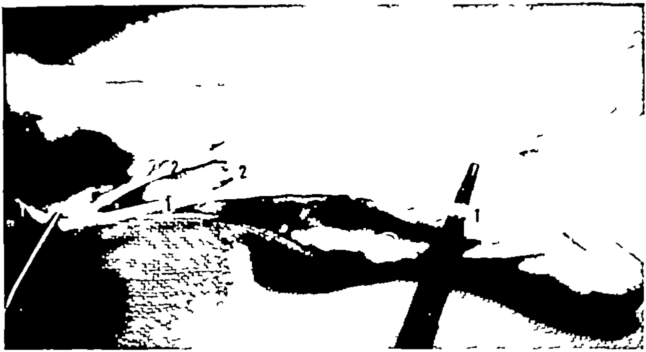

Fig. 35. Lateral view of the index finger to illustrate the proper digital nerve. 1 Proper digital nerve. 2, Dorsal branches of the proper digital nerve. These branches supply the dorsal surface of the finger distal to the proximal interphalangeal joint.

Fig. 36. Lateral view of the index finger to illustrate the long flexor tendons and their vincula. 1 Flexor profundus tendon. 2, One of the two slips of the flexor sublimis tendon. 3, Vinculum breve. 4, Vincula longa. 5, Cut edge of flexor tendon sheath.

lies on the proximal portion of the volar interosseus muscles and the proximal shaft of the metacarpals. It closely parallels the deep palmar arch in the central portion of the palm but is slightly proximal to the vascular arch.

The radial nerve to the hand has no motor components. It supplies sensation as far ulnarward as the midline of the dorsum of the long finger and distally along the dorsum of the index and long fingers as far as the proximal interphalangeal joint. The dorsal surface of the distal phalanx of the thumb may also have its main sensory innervation from the radial nerve. (Fig 34.)

The proper digital nerves to each finger are the main sensory supplies to the digit (Fig 35). As the digital nerve passes distally along the finger it lies on the volar side of the proper digital artery. There

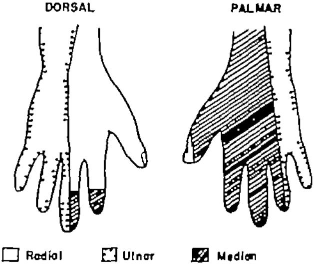

Fig. 34. Schematic drawing showing the common sensory distributions on the palmar and dorsal surfaces of the hand

Fig. 35. Palmar side of the hand to illustrate the deep branch of the ulnar nerve. The palmar aponeurosis, superficial arch nerves, and all the long flexor tendons have been removed. 1, Ulnar nerve. 2, Superficial branch (proper digital nerve). 3, Deep branch of the ulnar nerve showing some of its divisions. 4, Deep palmar arch. 5, Transverse head of the adductor pollicis muscle. 6, Flexor pollicis brevis muscle. 7, First dorsal interosseus muscle. 8, Abductor pollicis brevis muscle. 9, Volar carpal canal. The transverse carpal ligament has been removed.

by the relationship between the major artery and nerve has been reversed in comparison to the palm of the hand. Opposite the distal portion of the proximal phalanx of each finger the proper digital nerve gives off branches to the dorsal surface of the finger. There is usually one major branch and many smaller branches as the nerve courses distally. Sensation to the finger, therefore, over the middle and distal phalanges of the dorsal surface is supplied by the proper digital nerve of the individual finger.

Tendons. There are two long flexor tendons to each of the four fingers (Fig 36). The most superficial of the group is the flexor sublimis tendon. The sublimis tendons have their insertion at the base of the middle phalanx of each of the fingers. Over the middle of the proximal phalanx each of the sublimis tendons divides into two slips, and through this hiatus in the tendon passes the flexor profundus tendon. The profundus tendon then continues distally down the volar aspect of the finger to its site of insertion at the base of the distal phalanx. In addition to the insertion into the middle and distal phalanges each of these tendons has a supplementary attachment through the vincula. Each tendon has a long and a short vinculum. The vinculum is a small, mesentery like structure which passes from the floor of the osteofibrous canal to the tendon and usually it will transmit a small blood vessel which is important in nourishment of the tendon. The excursion of the sublimis tendon in its full extent at the level of the wrist is approximately

Fig. 38. The thenar muscles. T The level of the interphalangeal joint of the thumb. 1 Median nerve. 2, Flexor sublimis tendons. 3 Cut edge of the transverse carpal ligament. 4, Opponens pollicis muscle. 5 Superficial head of flexor pollicis brevis muscle. 6, Abductor pollicis brevis muscle

The web space is a potential space for purulent material to collect in. This is a subcutaneous space in the webs between the fingers which communicates proximally with the connective tissue about the lumbrical muscles. This space communicates with the subcutaneous area of the dorsal surface of the finger

INTRINSIC MUSCLES OF THE HAND

Thenar Muscles. The most superficial of these muscles is the abductor pollicis brevis (Figs. 31 38 and 39) Its origin is from the transverse carpal ligament and *greater multangular* The insertion of the abductor pollicis brevis is into the extensor hood and into the radial aspect of the base of the proximal phalanx of the thumb. Its nerve supply is from the recurrent branch of the median nerve The abductor pollicis brevis has full function of opposition of the thumb. If we will consider opposition as abduction and rotation of the first metacarpal, rotation and lateral deviation of the proximal phalanx with slight extension of the distal phalanx, it is apparent that the abductor pollicis brevis is the only muscle capable of performing the complete act of thumb opposition.

The opponens pollicis lies deep to the abductor pollicis brevis (Fig 38) Its origin is from the transverse carpal ligament and the greater multangular Its insertion is into almost the entire length of the shaft of the first metacarpal. This muscle also is supplied by the recurrent branch of the median nerve.

The flexor pollicis brevis is composed of two heads (Fig 38) The superficial head of the flexor pollicis brevis has its origin from the greater multangular and inserts into the radial side of the proximal phalanx of the thumb Its nerve supply is from the recurrent branch of the median nerve. The deep head of the flexor pollicis brevis has its origin from the lesser multangular and the capitate Its insertion is into the proximal phalanx of the thumb, but this portion is usually supplied by the ulnar nerve

The adductor pollicis also has two heads The transverse head has its origin from the third metacarpal and inserts in common with the oblique head into the ulnar side of the base of the proximal phalanx The transverse head is supplied by the

2½ inches, while the excursion of the profundus tendon is approximately 2¾ inches.[2]

In the fingers the long flexor tendons pass through a tendon sheath (Fig 37) In the case of the index, long and ring fingers, this sheath originates at the level of the metacarpal neck and terminates at the distal interphalangeal joint near the site of the insertion of the flexor profundus tendon. Strengthening the flexor tendon sheath are annular and cruciate ligaments which act as pulleys to keep the tendons from bowstringing when the finger is flexed. *In the case of the thumb and the little finger* a definite tendon sheath extends from above the transverse carpal ligament to the sites of insertion for the long flexor tendons. The tendon sheath of the little finger is often referred to as the ulnar bursa. The ulnar bursa at the level of the wrist joint is expanded to incorporate, into a synovial-like lining *the finger flexor tendons as they pass through the* volar carpal canal. In some instances, at the level of the wrist there is a direct communication between the radial and ulnar bursae. These bursae and their interrelations are quite variable and the reader is referred to Kanavel's monograph for a more detailed description of these variations.

Fig. 37 Flexor surface of the long finger showing the flexor tendon sheath 1 Flexor sublimis 2, Origin of flexor tendon sheath 3, Annular ligament 4 Cruciate ligament 5, Proper digital nerve

The flexor pollicis longus tendon at the level of the wrist is the most radial and the deepest of all structures passing through the volar carpal canal. *The tendon is encased in a tendon sheath* and has its insertion at the base of the distal phalanx of the thumb. The function is to flex the interphalangeal joint as well as the metacarpal phalangeal joint of the thumb. This tendon has an excursion of approximately 2 inches. The flexor digitorum sublimis is innervated by the median nerve. *The flexor pollicis longus and the flexor profundus* to the index and long fingers are supplied by the median nerve. The ulnar nerve innervates the major portion of the flexor profundus going to the ring finger and little finger

Palmar Spaces. In the palm of the hand, there are three distinct spaces which may be involved in infection. The first of these is the thenar space, which has as its ulnar boundary the septum extending from the palmar aponeurosis to the shaft of the *third metacarpal. On the radial side it is bounded* by the flexor pollicis brevis. This potential space is to the palmar side of the adductor pollicis, but lies deep to the long flexor tendon to the index finger

The mid palmar space lies to the ulnar side of the hand with its radial boundary being the septum to the third metacarpal. *Its floor when looking at* it from the volar aspect of the hand would be the superficial fascia which overlies the metacarpals and the interosseus muscles on the ulnar side of the hand The ulnar boundary is the hypothenar muscle group. This potential space also lies deep to the long flexor tendons passing to the long ring and little fingers.

Fig. 40. Volar aspect of the hand. All nerves, vessels and tendons have been removed. 1 Flexor carpi ulnaris tendon. 2 Flexor carpi radialis tendon. 3 Volar carpal canal. 4 Cut edge of the transverse carpal ligament. 5, Opponens pollicis muscle. 6 Flexor pollicis brevis muscle. 7 Origin of abductor pollicis brevis muscle. 8, Abductor digiti quinti muscle. 9, First dorsal interosseus muscle. 10, First volar interosseus muscle. 11 Second volar interosseus muscle. 12, Third volar interosseus muscle. m, Metacarpals (2, 3 and 4)

Fig. 41 1 The four lumbrical muscles. 2, Flexor profundus tendon to the index finger. 3, Flexor profundus tendon to the long finger. 4 Flexor profundus tendon to the ring finger. 5, Flexor profundus tendon to the little finger

Fig. 42. The hypothenar muscles. A clearly defined flexor digiti quinti could not be identified. RF Ring finger. LF Little finger; 1 abductor digiti quinti muscle. 2, opponens digiti quinti muscle

Fig. 39 Dorsal view of the base of the thumb showing the insertion of the abductor pollicis brevis. T The level of the interphalangeal joint of the thumb 1 The abductor pollicis muscle. 2, Origin of the tendon of the abductor pollicis brevis. 3 The portion of the tendon of abductor pollicis brevis contributing to the extensor hood of the thumb. 4, Extensor hood of the thumb. 5 Extensor pollicis brevis tendon. 6, Extensor pollicis longus tendon.

ulnar nerve. The oblique head of the adductor pollicis has its origin from the transverse carpal ligament, the capitate, and the base of the second and third metacarpals. Its insertion is in common with that of the transverse head. The oblique portion is also supplied by the ulnar nerve.

Interosseus Muscles. There are two groups of interosseus muscles. the volar and the dorsal divisions (Fig 40) The volar interosseus muscles are three in number one for each—the index, the ring and the little fingers. They have their origin from the shafts of the second, fourth and fifth metacarpals. The insertion of each volar interosseus muscle is somewhat complicated, since it has three rather distinct sites of insertion first, it sends a slip to the joint capsule at the metacarpophalangeal joint second, it sends a slip of inserting fibers into the base of the phalanx third, there is a definite portion which has its insertion into the extensor hood of the finger The function of the volar interosseus muscles is adduction of the finger plus the function of the extensor hood This entire group of muscles is supplied by the ulnar nerve

There are four dorsal interosseus muscles one for the index and one for the ring finger and two for the long finger The origin of the dorsal interosseus muscles is from both sides of the interosseous spaces. The insertion is the same as for the volar interosseus muscle group, except in the case of the first dorsal interosseus. The first dorsal interosseus muscle has its insertion entirely into the radial side of the base of the proximal phalanx of the index finger The function of these muscles is abduction of the fingers plus the function of the extensor hood. This group of muscles also is supplied by the ulnar nerve.

Lumbrical Muscles. There are four lumbrical muscles in the palm of the hand (Fig 41) These muscles have their origin from the flexor profundus tendons as they course through the palm of the hand. There is a double origin for the lumbrical muscles to the ring finger and little finger The course of the lumbrical tendons is to the radial side of each corresponding metacarpal. The tendon passes through the so-called lumbrical canal, volar to the transverse metacarpal ligament, and then

Fig 40 Volar aspect of the hand. All nerves, vessels and tendons have been removed. 1 Flexor carpi ulnaris tendon. 2, Flexor carpi radialis tendon 3 Volar carpal canal. 4 Cut edge of the transverse carpal ligament. 5, Opponens pollicis muscle 6, Flexor pollicis brevis muscle 7 Origin of abductor pollicis brevis muscle 8, Abductor digiti quinti muscle 9 First dorsal interosseus muscle 10, First volar interosseus muscle 11 Second volar interosseus muscle 12, Third volar interosseus muscle m, Metacarpals (2 3 and 4)

Fig. 41 1 The four lumbrical muscles. 2, Flexor profundus tendon to the index finger 3 Flexor profundus tendon to the long finger 4 Flexor profundus tendon to the ring finger 5, Flexor profundus tendon to the little finger

Fig 42. The hypothenar muscles A clearly defined flexor digiti quinti could not be identified. RF Ring finger LF Little finger 1 abductor digiti quinti muscle 2, opponens digiti quinti muscle

curves dorsally to insert into the extensor hood. The angle of approach of the lumbrical tendon in relationship to the finger in full extension is approximately 35 degrees. The lumbrical muscles to the index and long finger are supplied by the median nerve, while those of the ring finger and little finger are supplied by the ulnar nerve. The function of the lumbrical muscle is in part the function of the extensor hood and it is one of the best flexors of the metacarpophalangeal joint.

Hypothenar Muscles. The final group of intrinsic muscles of the hand consists of the hypothenar muscles (Fig 42) The most prominent of these is the abductor digiti quinti. This muscle has its origin from the pisiform and the hamate with its insertion into the base of the proximal phalanx and into the extensor hood of the little finger The function of this muscle is abduction of the little finger plus the function of the extensor hood. It is supplied by a branch from the deep ulnar nerve. The second muscle in the hypothenar group is the opponens digiti quinti. This muscle has its origin from the hamate and transverse carpal ligament. Its insertion is into the ulnar border of the entire length of the shaft of the fifth metacarpal. The function is slight opposition of the little finger It is supplied by a branch from the deep ulnar nerve. The flexor digiti quinti brevis is the third muscle of the hypothenar group. It has its origin from the hamate and transverse carpal ligament and is inserted frequently in common with the abductor digiti quinti. Its function is to slightly flex the phalanx of the little finger According to Morris it may be absent in approximately 18 per cent of individuals.[9] When present, it is supplied by the ulnar nerve. Many times it can not be separated from the abductor digiti quinti

EXTENSOR HOOD OF THE DIGITS

The extensor hood of each of the four fingers is a complex mechanism with multiple component parts (Fig 43) The component parts of the extensor hood consist of the long extensor tendon to each finger the volar and dorsal interosseus muscles to each finger and the lumbrical muscles which approach from the radial side. The first dorsal interosseus muscle has its insertion entirely into the bone of the proximal phalanx of the index finger The other interosseus muscles insert into the metacarpophalangeal joint capsule into the base of the proximal phalanx and into the extensor hood. The lumbrical muscle inserts into the radial side of the extensor hood with an approach of approximately 35 degrees from the volar aspect of the transverse metacarpal ligament.

The structure of the extensor hood is also complicated (Figs. 43 44 and 45) Overlying the metacarpophalangeal joints and across the very proximal portion of the base of the proximal phalanx are transverse fibers. These blend into the oblique fibers that extend along the lateral margins of the proximal phalanx and beyond the proximal interphalangeal joint. Over the central dorsal surface of the

Fig. 43 Dorsal surface of the extensor hood of the index finger 1 Extensor indicis proprius tendon. 2, Extensor digitorum communis tendon. 3 Lumbrical tendon. 4, First volar interosseus tendon. 5, First dorsal interosseus muscle. 6, Fibrocartilaginous disc at site of ventral slip insertion. 7 Triangular ligament 8, Lateral bands. 9, Site of insertion into distal phalanx. 10, Transverse fibers. 11 Oblique fibers.

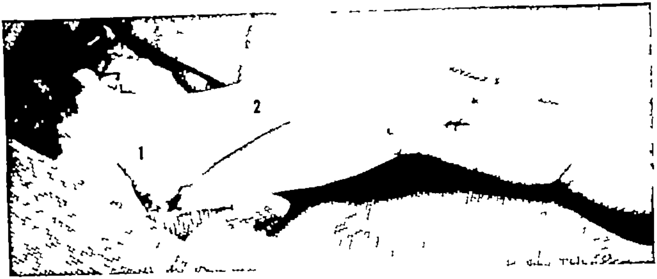

Fig. 44 Lateral view of the extensor hood of the index finger 1 Transverse fibers. 2, Oblique fibers.

Fig. 45. Lateral view of finger with the extensor hood elevated to show its various divisions. 1 Central slip inserting into the dorsum of the middle phalanx. 2, Distal continuation of the lateral bands 3 Distal portion of the triangular ligament. The proximal portion has been removed 4 The portion of the extensor hood which overlies the proximal phalanx. 5, Distal portion of the extensor hood going to its insertion into the base of the dorsal surface of the distal phalanx.

Fig. 46. Lateral view of the proximal interphalangeal joint. All capsular and ligamentous soft tissue has been removed. 1 Proximal phalanx. 2, Middle phalanx. Note how the middle phalanx glides around the head of the proximal phalanx.

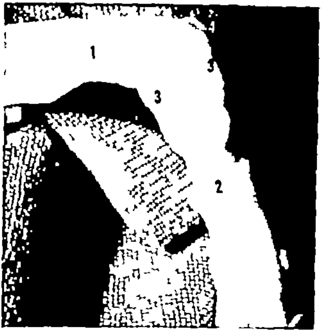

Fig. 47 Lateral view of proximal interphalangeal joint to illustrate the collateral ligament. All capsule of the joint has been removed, leaving only the collateral ligament. 1 Proximal phalanx. 2, Middle phalanx. 3, Expanse of the collateral ligament. 4 Articular surface of the proximal phalanx.

fingers, the extensor hood just proximal to the proximal interphalangeal joint divides into three parts, the central portion going to its insertion into the dorsal surface of the middle phalanx. This inserting band of the extensor hood is intimately associated with the fibrocartilaginous plate over the proximal interphalangeal joint. The two lateral bands separate, passing over the dorsolateral aspects of the joint, and then over the middle phalanx approach each other again. The lateral bands join at the site of insertion into the dorsal surface of the distal phalanx. The lateral bands are held together over the dorsal surface of the middle phalanx by the so-called triangular ligament. Bunnell quotes Kaplan as observing that, in 38/6 per cent of the hands he studied there was also a central slip of insertion into the base of the proximal phalanx.

Bunnell has made an extensive study of the function of the extensor hood, and the reader is referred for a more detailed description of this function to his book. In general the function of the extensor hood can be summarized as follows. It has the ability to flex the proximal interphalangeal joint, and this takes place when the extensor hood has been shifted into a distal position by relaxation of the long extensor tendons. The chief muscle that has the ability to flex the metacarpophalangeal joint is the lumbrical muscle this is due to its approach from the volar aspect of the joint. The interosseus muscles have considerably less function as flexors of the metacarpophalangeal joint. When the long extensor tendon has shifted the entire hood into a more proximal position, the interosseus muscles then have the chief function of extension of the proximal and distal interphalangeal joints. The long extensor tendon's main function is extension to the metacarpophalangeal joint. However it should be remembered that when the metacarpophalangeal joint is held in 20 to 40 degrees of flexion and is not allowed to hyperextend, the long extensor tendon has complete capability of extending the proximal and distal interphalangeal joints.[3, 8]

METACARPAL AND INTERPHALANGEAL JOINTS

The metacarpophalangeal and the interphalangeal joints represent a gliding diarthrodeal articulation (Fig 46). The range of motion is from 180 to 90 degrees. As a diarthrodeal joint it is surrounded by a capsule which is lined by synovium. On the lateral surfaces, the joint capsule is markedly thickened to form the collateral ligaments (Fig 47). The collateral ligaments are attached to the com-

ponent portions of the joint in such a fashion that when the joint is extended the collateral ligaments are somewhat relaxed and when the joint has reached 90 degrees of flexion the collateral ligaments are tight. The joint capsule is also thickened on the volar aspect, which forms a so-called volar plate of the interphalangeal joints. In addition there is some laxity or redundancy of the volar capsule surface in order to accommodate the distal phalanx as it glides into a position of 90 degrees of flexion.

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DUPUYTREN'S CONTRACTURE
Pathogenesis and Surgical Management: A New Concept

The method of surgical management herein described has been used since 1947 It is based on a new concept of the pathogenesis which grew out of protracted study of the pathological anatomy of Dupuytren's contracture[4] This surgical management is far more limited and more conservative than the radical procedure that is now used almost universally

In the clinical picture of this entity contractures of the fingers and palms are the most prominent manifestation. The incidence is much higher in men than in women and, for the most part, it is a disease of middle and old age. The disease may occur at any time after the second decade, but the highest incidence is in patients more than 50 years of age. At onset the disease is characterized by the appearance of one or more nodules either in the palm or in the proximal one-third of the fingers. The right hand is more frequently involved than the left. The majority of patients have no pain and no tenderness although an occasional patient has considerable disability from these symptoms The highest incidence of nodules and subsequent contractures is in the ulnar half of the palm and the small and ring fingers Involvement of the thenar eminence with contracture of the thumb is not uncommon. The lowest incidence of involvement is in the index finger

The differential diagnosis is not a problem. Stenosing synovitis rheumatoid arthritis, and paralytic contractures bear this entity only a superficial resemblance. Involvement of the plantar fascia and penis is by no means rare and is characterized by the same nodules and the same histological features as are noted in the hands. Contractures in the feet are rare and contractures of the toes have never been observed by this writer

ETIOLOGY

Many etiological factors have been indicted, but not one has been proved, with the exception of heredity There can be little doubt about the hereditary factor this factor being present in from a small percentage to as high as 40 per cent in the various series of cases reported in the literature. Trauma has been one of the most discussed of the alleged etiological factors and has had many proponents. Actually trauma as a true etiological factor has little to support it. It has not been unusual for a patient with Dupuytren's contracture to have involvement of both hands and both feet. Such distribution would be difficult to attribute to trauma. Likewise explanation on the basis of inflammation or infection has no valid proof The various theories of the etiology are too numerous to review in this type of report

PATHOGENESIS

While the etiology is unknown there is much in the pathogenesis that is becoming understood and such observations have important application to

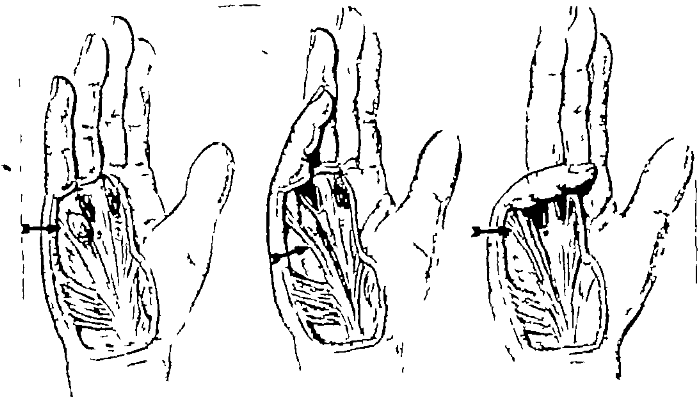


Fig 48. A, Nodule in proliferative stage B, Nodule involuting with contraction and reactive cord formation proximal to nodule. C, Residual stage. Nodule now completely involuted, has disappeared, leaving contractures and hypertrophied band of palmar fascia.

clinical management of the disease. In the concept to be herein described the nodule will be viewed as the essential lesion and the site of all of the contracture The fibrous cords, so conspicuous in this disease, will be viewed as reactive. The highly important nodules of this entity undergo conspicuous changes in their life history These changes will be described as three stages (Fig 48) (A) proliferative stage (B) involutional (contracting) stage and (C) residual stage.

Proliferative Stage. It is in this stage that the nodule is first seen. Histologically it is made up of young appearing fibroblasts which have no alignment with lines of stress and which resemble the fibroblasts of a fibroma (Fig 49) There is no proof that the lesion represents a tumor and the subsequent fate of the nodule is not that of a tumor Solitary nodules occur but in the majority of cases nodules are multiple These nodules reside on or in the fascia in the side facing the skin. As the nodule enlarges it bears against the deep layers of the skin, often replacing them, and ultimately fusing the overlying skin and the underlying fascia. Growth occurs by expansion If a nodule forms at the site of a skin crease, the nodule frequently will have the appearance of twin nodules with half of the nodule bulging out on each side of the transverse skin crease. While nodules may appear anywhere in the palm, the majority occur in the distal one half of the palm. It is common for a nodule to appear in relationship to the proximal interphalangeal joints of the fingers (Fig 50) The writer has never observed a nodule in relationship to the distal interphalangeal joint. Nodules in rare instances, occur on the dorsum of the proximal interphalangeal joints. These so-called knuckle pads have the same histological appearance as the palmar nodules.

Involutional Stage. After the nodule reaches a certain size which varies widely from 2 or 3 mm. to as much as 1 or 2 cm the nodule ceases to grow and undergoes changes, which can be best described as an involutional process. During this involutional stage a contracture of the nodule occurs Fibroblasts in the nodule decrease in number tend to become more mature and align themselves with the major lines of stress transmitted by the tissue and the collagen element becomes more prominent If we visualize a nodule in the palm, overlying the

Fig. 49. Histological appearance of fibroblasts in a nodule in the proliferative stage

fourth metacarpophalangeal joint, we will see the following sequence of events. The skin overlying a nodule will be securely transfixed to the underlying palmar fascia. As the nodule undergoes its contraction, the skin of the palm will be drawn into deep corrugation and the metacarpophalangeal joint, readily yielding to the contracture, will gradually develop a flexion contracture. If the ring finger is then forcibly extended at the metacarpophalangeal joint, it will be noted that there is a distinct tugging on that band of palmar fascia extending from the nodule to the apex of the palmar fascia. Intermittent tugging on this band of fascia occurs each time the patient lifts something or in any way extends his fingers. Patients with Dupuytren's contractures frequently preoccupy themselves with attempts to forcibly stretch the contracture. It is in this involutional stage that we see the cord making its appearance and it is the writer's contention that this cord is reactive and not an aggressive part of the disease as has been believed in the past (Fig. 51). It is the writer's argument that this cord represents hypertrophy of the normal palmar fascia in response to the intermittent tension stresses placed upon it. This is a radical departure from previous concepts and has far-reaching implications in treatment. These implications are readily understood when it is realized that in the radical approach strict care is given to resecting all of these cords and their related digitations.* This adds immensely to the scope of surgery. In the writer's concept, as will be described in detail, these cords which are classified as reactive are merely divided—not resected.

Reactive cords form only proximal to the nodule, not distal to it. However, multiple nodules, with reactive cords in between, are more common than the single nodule with the single reactive cord. Nodules and their cords will be referred to as nodule-cord units. It is frequent to see a chain of nodule-cord units consisting of two, three or more nodules and cords. When a hand is examined and nodules are found, it is possible to predict with reliance the potential contracture in the nodules. Nodules in the palm can cause only, at most, contractures of the metacarpophalangeal joints. It is not possible for a nodule in the palm to cause any significant degree of contracture of the interphalangeal joints. To have a contracture of the proximal interphalangeal joint, it is necessary that a nodule develop over or adjacent to this joint. The more nearly the nodule resides directly over the joint, the more its potential contracture. Conversely, the farther the nodule develops from a given joint, the less its potential contracture. This is why the nodules that occasionally occur in the proximal palm have little capacity in their life history to create a contracture. Actually, the nodules in relationship to the proximal

Fig. 50. Arrows point to nodules.

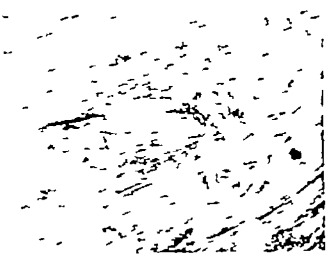


Fig. 51 Histological appearance of fascial band that has undergone reactive hypertrophy forming a fibrous cord.

interphalangeal joint present the most complex problems in this entity not the palmar involvement which has been so much stressed and discussed in medical literature.

Whenever we see a finger flexed into the palm, it means that there have been at least two nodules in the chain involving the finger one in the palm in relationship to the metacarpophalangeal joint and one in the finger in relationship to the proximal interphalangeal joint. There are sites at which the contracture created is not a flexion contracture, but rather an ulnar or radial deviation of the fingers. Such an instance is seen when a nodule occurs over the medial aspect of the fifth metacarpophalangeal joint. This causes the small finger to separate from the ring finger in an abduction contracture, a contracture that is decidedly objectionable to the patient.

It is not unusual for nodules to cause two fingers to be drawn together so that no appreciable separation of the fingers is possible. When this occurs, it is usually between the small and the ring finger or between the ring finger and long finger. A nodule occurring over the first metacarpophalangeal joint may occur at one of several sites. If it occurs directly anteriorly the cord extends through the thenar eminence. If it occurs more laterally toward the web, the cord will extend through the web of the thumb. This latter cord is rounded and well defined. Cords that extend through the thenar eminence proper are usually somewhat broader and are flat. The characteristic of the reactive cord, so far as being flat or rounded is concerned depends on the looseness or tightness of the skin through the course of the cord. When nodules occur in chains the most distal nodule in the chain has a cord extending proximally to the next nodule and that nodule has a cord extending to the next. The last nodule in the palm is characterized by a cord extending proximally to the apex of the palmar fascia.

A clear picture of how much contracture of the skin and underlying joint can occur from a relatively small contracture of a mechanically advantageously placed nodule may be obtained by pinching the skin overlying either the proximal interphalangeal joint of a finger or a metacarpophalangeal joint. It will be noted that when this skin is pinched and thus shortened for as little as one fourth of an inch, there is a substantial contracture in the joint. Pinching the skin and shortening it over the proximal interphalangeal joint for as small an extent as one fourth of an inch can cause 45 or more degrees of contracture of that joint. It is the writer's contention that no contracture whatever occurs in the cords proximal to the nodule when there are no areas of the cord containing nodular fibroblastic foci. The propensity of fascia to hypertrophy under intermittent tension stresses is seen in other situations. The writer has seen a burn in the distal palmar crease cause a focus of contracture and a fusion of the skin to the fascia. This was associated with a reactive fibrous cord extending to the apex of the palmar fascia. A striking illustration of this same phenomenon is seen in fascial transplants in the abdominal wall. This is the LeRoy Lowman operation in which fascia lata straps are extended from the tenth rib crisscross to the anterior superior spine of the ilium. These fascial straps undergo the most pronounced degree of hypertrophy which is due to the intermittent tension stresses transmitted by the straps. Each time the patient takes a step there is a sharp tug on one fascial strap or the other as these straps connect the rib cage to the pelvis. It is not unusual to see them hypertrophied to the thickness of a heel cord. What convincing proof this is of the capacity of fascia to hypertrophy under intermittent tension stresses! The rate at which nodules undergo their involution and contraction is widely variable. There can be a slow and steady involution or involution characterized by long periods of quiescence. After variable periods of quiescence, and for no apparent reason, the nodule or nodules can begin again to involute and contract.

There have been instances where nodules re

mained unchanged for ten to twenty years and then underwent contraction. The greater the contracture present, the more likely that the involution is far advanced or even complete. Very small nodules have less capacity to cause contracture as compared to the potential contracture in larger nodules. Many nodules contract virtually their entire diameter.

There have been instances in which the writer acquired the impression that as a result of trauma to a given nodule or nodules, particularly those overlying joints and particularly when the trauma represented heavy pressure of hard objects, the nodule was precipitated into either a contraction phase or a more accelerated contracture. However, the ultimate degree of contracture acquired did not seem influenced by the trauma, and most certainly the nodule did not appear to have been caused by the trauma. This accentuation of the rate of contracture from trauma may explain why the incidence of contracture is higher in the right hand than in the left. With progressive involution and contracture, the nodule becomes harder and smaller and, in many instances, ultimately disappears.

Nodules in different parts of the palm and fingers can be of a different age and present different rates of involution. With these wide variables, it is not surprising that the microscopic picture of Dupuytren's contracture has not been a previous basis for reconstructing the pathogenesis. Skoog, in his comprehensive monograph on Dupuytren's contracture published in 1948, concluded: "It was not possible to establish any relation between the histological picture and the clinical features of the disease."[73]

Fig. 52. Large nodule in the plantar fascia. Hyperextending the first toe tenses the plantar fascia and makes the nodule more prominent.

Nodules in the plantar fascia tend to be larger and more neoplastic in their appearance than the nodules in the palm (Fig. 52). There is also a greater tendency for the nodule to remain for a long period in the proliferative stage. However, the writer has observed several well-defined instances in which the nodule of the plantar fascia underwent involution with cord formation. The cords usually have been observed near the medial border of the plantar fascia. In a few instances, nodules in both the hand and the foot have been observed to undergo involution with little, or no, contractures.

Contractures in the approximately 200 cases of this writer's personal experience have been divided into three grades. Grade I contractures are those of from 5 to 30 degrees. Grade II contractures are those between 31 and 60 degrees and Grade III contractures are those between 61 and 90 or more degrees. The joint having the greatest degree of flexion contracture determines the grade given the case. More complex classifications may have their good points, but the classification here presented has simplicity in its favor.

Residual Stage. In many instances, and particularly evident in older patients, the nodule completely disappears during the involutional process. In these instances, the nodule creates the maximum contracture of which it is capable during the process of destroying itself. All that is left histologically in these instances is the relatively acellular fibrous cord. The contracture of the skin and the joint, besides the numerous adhesions surrounding the sites of the previous nodules, is all that remains. This stage has been termed the residual stage. The disease has burned out, leaving the contractures in its wake.

The more stresses that are exerted on the reactive cords, the heavier they become. Likewise, fibrous cords that have ceased to be subjected to intermittent tension stress tend to atrophy. Several instances have been observed in which a finger was completely contracted into the palm, becoming utterly useless. Exploring the fibrous cords in these instances, particularly when they have been of long duration, it has been striking to see the smallness of the cords. In contrast, when the finger is flexed only part way into the palm and subjected to frequent and strong tension stress such as occurs in laborers, the fibrous cords become heavy and strong.

The metacarpophalangeal joints are not nearly so susceptible to irreversible joint changes as are the proximal interphalangeal joints. The proximal interphalangeal joint of the small finger can be the most troublesome problem in the management of this entity. After many years of contracture the capsule adapts itself by shortening on the flexion side; this occurs also in the vessels, nerves, and tendons.

Therapy. The ideal therapy for Dupuytren's involvement would be a method of treatment that would resolve the nodules when they are in the proliferative stage before the development of collagenous bands and contracture. Our goal should be to find this treatment. Nonsurgical treatments of the nodules in the proliferative stage are now being studied and these include ultrasonic therapy, roentgen therapy, injection of corticosteroids, et cetera. It must be obvious that to use these various methods, without recognition of the stage of the disease, would be to invite the most unreliable evaluation of them. The medical literature is replete with evaluations of these various nonsurgical methods without any regard for the stage of the process. It is the writer's conviction that these nonsurgical methods should be used only in the proliferative stage or in the early periods of the involutional stage. After the nodules have destroyed themselves or when they are approaching the residual stage, there is little reason to anticipate resolution of the contractures by anything other than surgical methods.

SURGICAL THERAPY

The method of surgical management recommended has been used since 1947 and is based on the concept of the pathogenesis herein described. In the proliferative stage, a solitary small nodule in the palm is usually not treated surgically but rather is treated by nonsurgical methods or sometimes merely observed. If there is a large nodule and it is soft, and particularly if it is tender, it is treated by the injection of hydrocortisone or by ultrasonic therapy or even by x-ray therapy. If the nodule, even though solitary, is located immediately over a metacarpophalangeal joint and appears destined to cause a disabling contracture, it may be enucleated using care to not leave any portion of the nodule behind. Patients are informed that this does not give them an immunity from development of nodules in other parts of the hand. It has been an interesting observation that other nodules have developed in far less than half of the cases. It is by no means a foregone conclusion that the presence of one or two nodules will be ultimately followed by other nodules and other contractures. This is a widespread but erroneous concept. A great many patients seen by the author have been living under the misapprehension that at any time they would quickly and with certainty develop severely disabling contractures. Observations over the years have not confirmed this erroneous contention.

A nodule directly over or adjacent to the proximal interphalangeal joint should not be left to its own devices. Once it starts to involute, this nodule should be excised by a relatively short mid-lateral or mid-medial incision centered at the nodule. Such a nodule may be located in the midline, but very frequently it is located eccentrically, overlying and frequently enveloping digital nerves and vessels. In visualizing these nodules in the fingers, the digital nerve should first be identified either proximal or distal to the nodule, and the nerve and vessels then carefully dissected free. With the nerve and vessels retracted, the nodules should be meticulously excised. The sheath of the tendon frequently is fused to the nodule and must be excised. The skin is undermined at the site of the nodule with care taken not to include a portion of the nodule with the skin. In exceptional instances, an incision is required in both the medial and lateral aspects of the finger at the site of the nodule. A second incision is avoided whenever possible. These mid-lateral and mid-medial incisions heal rapidly, and there is almost no tendency for circulatory embarrassment. If a contracture is present at the proximal interphalangeal joint, then there is likely to be a cord proximal to the nodule. A portion of this cord can be removed with the nodule.

In the palm, when nodules are in the involutional stage, with cords proximal to the nodule extending (as they do) to the apex of the palmar fascia, these cords are sectioned by subcutaneous fasciotomy. This technique is carried out with a fasciatome resembling an eardrum knife (myringotome). The technique of using the fasciatome must be learned in detail, and it must be used with the same respect that is employed in open surgery. A small puncture is made in the skin on the ulnar border of the hand starting in the proximal one-half of the palm. The blade is passed subcutaneously with the blade transversely placed. When the blade reaches the border of the palmar fascia, it is turned so that the cutting edge of the blade lies against the fascia and the back

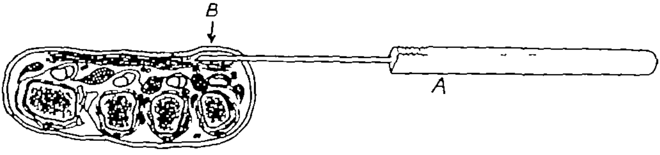


Fig. 53. A, Cross section, mid-palm level showing the fasciatome beneath the skin. Note triangular handle of the fasciatome. This tells the operator the location of the sharp edge of the blade when it is beneath the skin. B, Arrow indicates the direction of pressure to be applied by the surgeon's finger to the skin overlying the back of the blade. Finger is kept extended to make the cord taut as the blade is pushed through the cord.

of the blade lies against the overlying skin (*Fig 53*). With the blade in this position, and with the cord made taut by extending the contracted finger or palm, the blade is pushed through the taut fascia by the tip of the surgeon's index finger. Once the blade passes through the taut fascia, it presses against the underlying vessels, tendons, and nerves, but it does them no harm. Once the instrument has passed through the gritty resistance of the fascia, resistance ceases and it is as though the blade were being pressed against sponge rubber. Obviously once it has been pressed through the fascia and the resistance has stopped, no further pressure should be exerted. The blade is next advanced transversely another one-eighth or one fourth inch subcutaneously and then the cutting edge turned palmarward and pressed through the taut fascia. This is continued until the sectioning of the involved area is completed.

Under no circumstances should a reciprocal type of movement be used. This could be catastrophic and *obviously could sever the underlying structures.* The subcutaneous technique is safe in the palm only when the blade is *pressed* through the taut fascia. All sawing or reciprocal action must be studiously avoided.

After carrying out the first subcutaneous fasciotomy proximal to the proximal transverse palmar crease together with undermining any foci where the skin is fused to the cord, a second subcutaneous fasciotomy is usually carried out at a level between the transverse creases. The fasciotomy is carried out *to a point just proximal to the site of nodules* when the process is in the involutional stage. Where there is a deep crease in the skin, it is best to divide the cord proximal to this crease before undermining the skin at the site of the crease. If the undermining is carried out first, there is a chance of perforating the skin at the apex of the crease. If the fasciotomy is carried out first, then the crease becomes much shallower and the undermining can be done with clear visualization of the apex of the crease. Subcutaneous fasciotomy can be carried out somewhat distal to the distal transverse crease but should not be carried out in the region of the finger webs. Using the fasciatome around the webs endangers the nerves and vessels. Subcutaneous fasciotomy *is not* used in the fingers because of the danger to digital nerves and vessels. Whereas in the fingers the digital nerve or vessel frequently is encroached upon by a nodule, no such situation is found in the palm. Nodules do not develop on the deep surfaces of the palmar fascia but rather are limited to the superficial portion of the fascia with protrusion toward the skin.

The fasciatome has been employed at autopsies to learn the possibility of damaging underlying structures, and no damage has been inflicted. The subcutaneous fasciotomy when properly done is perfectly safe in the palm.

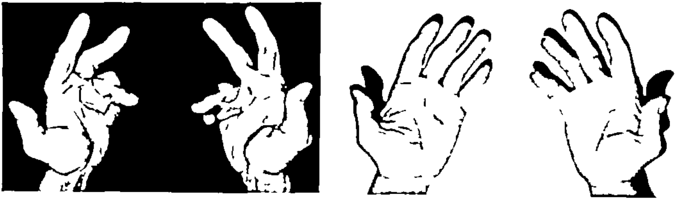
Subcutaneous fasciotomy was popular in the nineteenth century having been first used by Astley Cooper and reported in 1824. Dupuytren made multiple, short, transverse incisions through the skin and underlying fascial cords. The small skin incisions were left open. Adams, in 1878, did much to popularize subcutaneous fasciotomy. The method was abandoned at the end of the nineteenth century and the early part of the twentieth century giving way to radical methods of fascial resection. During the past half century surgeons have vied with each other to find more digitations to excise in extending the radical technique. The much more conservative approach herein presented has stood the

test of a decade of close observation and a large series of cases. There is little doubt that the reason the subcutaneous fasciotomy fell by the wayside is that it was used without recognition of the stage of the disease. If a subcutaneous fasciotomy is carried out in the palm and large nodules left in place there will generally be a recurrence of the contracture when the nodules left behind undergo involution.

Surgery on the palm, whether it be subcutaneous fasciotomy or the most radical technique that can be devised, will not correct contractures of the proximal interphalangeal joints. These contractures are the result of separate foci as above described and must be dealt with separately.

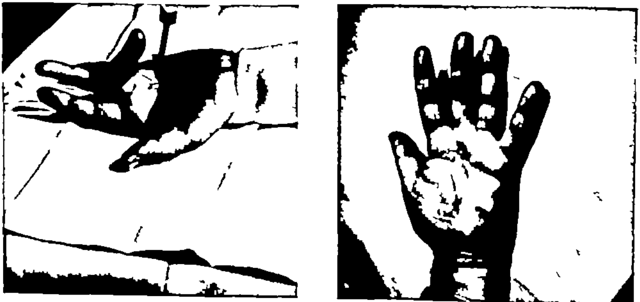
In the writer's series there have been no instances in which a skin graft was necessary. With this more conservative approach necrosis of the skin which has plagued surgeons carrying out the radical operation is not a problem.

In the residual stage of the disease, the palmar involvement is treated entirely by subcutaneous fasciotomy (Fig. 55). Finger involvement is treated by mid lateral or mid medial incisions in relationship to the proximal interphalangeal joint. Adhesions to the skin are undermined and a section of



A. B.

Fig. 54. A, Male 65 years of age preoperative view. B, Four years after subcutaneous fasciotomy and excision of nodules.



A. B.

Fig. 55. A, Residual stage. Arrow points to heavy fibrous cord, which represents hypertrophy of a band of the palmar fascia. B, Correction obtained by subcutaneous fasciotomy of palm and open sectioning of the cord in the finger.

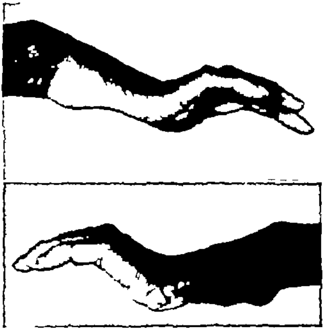


Fig. 56. Clawhand of median and ulnar nerve paralysis.

tension of the distal two phalanges from intrinsic paralysis results in the flexion deformity of the fingers. There is also a flattening of the palm due to the loss of the hypothenar muscles, but this is not functionally serious and in my experience does not need surgical repair. As will be explained later, if the proximal phalanges are stabilized at 180 degrees of extension or less, the claw deformity will not develop.

FUNCTIONAL ANATOMY

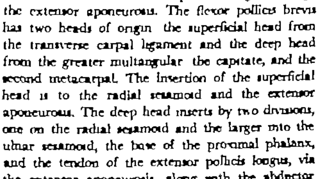
The present-day understanding of functional anatomy is due to development of the concepts of Duchenne, Bunnell, and Fowler. It is now accepted that normally the distal two phalanges are extended by both the long extensors and intrinsics synergistically. It is also agreed that if the proximal phalanx is stabilized at an angle of 180 degrees or less with the metacarpal, extension of the distal two phalanges may be accomplished by either the intrinsics alone, the long extensors alone, or both together. This concept explains why, in median nerve and ulnar nerve paralysis, a splint preventing hyperextension of the proximal phalanges allows the patient to extend the middle and distal phalanges by the pull of the long extensors. It also explains why some patients with median and ulnar nerve paralysis do not develop a clawhand because of tight joint capsules that do not allow hyperextension at the metacarpophalangeal joints. It also explains why a patient with radial nerve or dorsal interosseous nerve paralysis can extend the middle and distal phalanges by the functioning interossei and their ability to extend these two phalanges.

STRUCTURAL ANATOMY

Thenar Eminence. Most of the present-day text books of anatomy accurately describe the origin and insertion of the intrinsic muscles of the thumb, but few accurately illustrate the insertions of these muscles.

The abductor pollicis brevis takes its origin from the transverse carpal ligament and tubercle of the navicular. Its insertion is into the radial sesamoid bone (Fig. 57), the base of the first phalanx, and the tendon of the extensor pollicis longus through the extensor aponeurosis. The flexor pollicis brevis has two heads of origin, the superficial head from the transverse carpal ligament and the deep head from the greater multangular, the capitate, and the second metacarpal. The insertion of the superficial head is to the radial sesamoid and the extensor aponeurosis. The deep head inserts by two divisions, one on the radial sesamoid and the larger into the ulnar sesamoid, the base of the proximal phalanx, and the tendon of the extensor pollicis longus, via the extensor aponeurosis along with the abductor brevis tendon. (Figs. 58 and 59.)

Functionally, the abductor pollicis brevis is probably almost equal in power to the extensor pollicis longus in so far as extension of the distal phalanx of the thumb is concerned. This is easily seen in cases of radial nerve paralysis. Full extension of the



Anatomy of the
pollicis brevis
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showing insertion
pollicis longus. B,
Abductor pollicis
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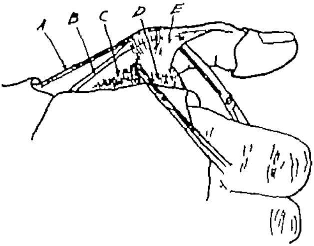


FIG. 58. Anatomy of ulnar side of thumb showing insertion of adductor into aponeurosis of the thumb. A, Extensor pollicis brevis. B, Extensor pollicis longus. C, First dorsal interosseus. D, Adductor pollicis. E, Extensor aponeurosis

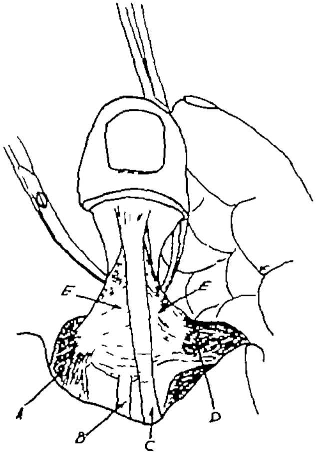


FIG. 59. Dorsal view of thumb showing aponeurosis relationship to extensor pollicis longus and brevis. A, Abductor pollicis brevis. B, Extensor pollicis brevis. C, Extensor pollicis longus. D, Adductor pollicis. E, Extensor aponeurosis

distal phalanx can be seen if the thumb is in opposition or if the thumb is stabilized by an external force in any position. The abductor pollicis brevis is then capable of extending the distal phalanx strongly. If the thumb is not stabilized, the thumb first goes into full opposition, the proximal phalanx deviates radially, and then extension of the distal phalanx occurs.

Interosseus Muscles. The interosseus muscles are located between the metacarpal shafts and are described as the dorsal and palmar or volar interossei according to their relation to the axis of the hand and position relative to the palmar and dorsal aspects of the intermetacarpal spaces.

The palmar interossei originate by a single belly from the palmar two-thirds of the metacarpal shaft facing the axis of the hand and insert on the proximal phalanx corresponding to the metacarpal origin. There are three palmar interossei and, therefore, all act as adductors toward the axis of the long finger.

The dorsal interossei originate from two muscle bellies from the adjacent metacarpal. The larger belly arises from the anterolateral surface of the metacarpal which faces away from the axis of the long finger. The smaller muscle is attached to the remaining third of the shaft of the metacarpal facing the axis of the long finger. The insertion of these muscles takes place on the proximal phalanx of the side of the larger origin of the muscle. The dorsal interossei are abductors of the fingers away from the axis of the long finger and are four in number.

The insertions of the palmar interossei are partly into the lateral tubercle of the base of the proximal phalanges, and the majority of the insertion is into the extensor apparatus by a tendon. This tendon expands and contributes to the fibers of the dorsal aponeurosis and connects with the mid portion of the extensor digitorum communis tendon and to the lateral band of the dorsal apparatus.

The dorsal interossei form a tendon which has one head inserting into the base of the proximal phalanx anterior to the axis of flexion and extension of the metacarpophalangeal joint (Fig. 60). The other part of the tendon is flat and approaches the dorsal apparatus with a twist; part of this tendon then continues on into the lateral bands of the dorsal aponeurosis, expanding and contributing to the fibers of this aponeurosis and the mid-band of the extensor digitorum communis tendon. The insertions of the dorsal interossei vary and it is usu

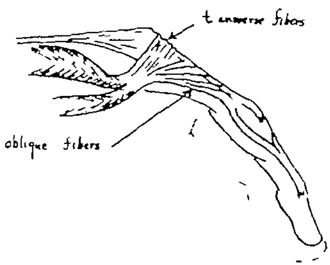


Fig. 60. Lateral view of finger showing relationship of extensor tendon and interossei and extensor mechanism. (From Harris, C., and Riordan, D. C. J. Bone & Joint Surg. 36-A: 10, 1954.)

ally found that the first dorsal interosseus may not have any insertion into the dorsal aponeurosis but inserts completely into the lateral tubercle at the base of the proximal phalanx of the index finger. The second and third dorsal interossei usually have the typical double insertion described above as does the fourth dorsal interosseus.

Hypothenar Eminence. The hypothenar eminence is a separate group of three muscles all inserting onto the little finger. The abductor digiti quinti originates from the distal part of the pisiform bone, from the pisiform hamate ligament, and from part of the volar carpal ligament. The muscle may have *what appears to be two muscle bellies, con*tinuing toward the base of the proximal phalanx of the little finger and forming a double tendon, one part inserting into the lateral tubercle on the ulnar side of the proximal phalanx and the other into the dorsal aponeurosis.

The flexor digiti quinti brevis originates from the volar carpal ligament, the hook of the hamate bone and from the pisiform hamate ligament. This muscle, which is tightly covered by the abductor, covers the muscle belly of the opponens digiti quinti. The insertion of this muscle is in front of the phalangeal insertion of the abductor on the anterior part of the lateral tubercle at the base of the proximal phalanx.

The opponens digiti quinti is a small muscle completely covered by the flexor belly, originating from the hook of the hamate bone and from the pisiform hamate ligament. The fibers of the muscle run toward the fifth metacarpal and insert by short slips into the whole length of the ulnar side of the shaft of the metacarpal. The deep branches of the ulnar artery and nerves pass through the fibers of this muscle.

Lumbrical Muscles. There are four lumbrical muscles situated on the radial side of the flexor tendons of the index, long, ring, and little fingers, respectively, and inserting into the radial side of the dorsal aponeurosis.

The normal origin of these muscles is from the tendon of the flexor profundus of the corresponding finger in the palm of the hand. The first and second lumbrical muscles arise from the radial border of the flexor profundus of the index and long fingers, respectively. The third and fourth lumbricales arise from the adjacent surfaces of the profundus tendon of the long and ring fingers and the ring and little fingers. The origin of these muscles on the flexor profundus covers a considerable distance and may be from 2 to 4 cm. in length. The muscle fibers run on the flexor side and the radial side of the tendon and may completely cover the sublimis tendon in the palm. The lumbrical muscles of the long, ring, and little fingers pass anterior to the *transverse metacarpal ligament between the second,* third, fourth, and fifth metacarpal heads. The lumbricalis of the index finger has no such ligament but maintains the same approximate position. The insertion of these muscles is into the fibers of the lateral band of the dorsal aponeurosis and forms an angle of approach of about 30 degrees from the flexor tendon. The tendon, therefore, lies anterior to the axis of motion of the metacarpophalangeal joint, and the tendon usually forms the leading edge of the dorsal aponeurosis on the radial side.

SURGICAL REPAIR

The Thumb

Methods of Transplantation. There are three me*chanical principles that must be fulfilled by* any transplant that aims to restore good opposition of the thumb. The first of these is that the pulley remain constant in its position and, in my opinion, that it maintain the tendon transfer *exactly at the point* where the normal palmaris longus passes the flexion crease of the wrist when the wrist is neither in radial nor in ulnar deviation. The second principle is that the tendon transplant pass subcutaneously across the thenar eminence superficial to the volar carpal liga

Fig 61 Marks on skin showing the three mechanical points mentioned which outline the course of the tendon transfer

ment and that it be maintained exactly over the center of the tendon of the abductor pollicis brevis at the level of the metacarpophalangeal joint This corresponds precisely to the insertion of the normal abductor pollicis brevis. The third principle is that the transplant continue distally into the tendon of the extensor pollicis longus, in the direction of the fibers of the abductor pollicis brevis, and end in the long extensor just proximal to the proximal inter phalangeal joint. (Fig 61)

Thus, it can be seen that the transplant is actually made to pass in a line running from the origin of the abductor pollicis brevis, through its tendinous part, over the metacarpophalangeal joint, and insert through the aponeurosis into the extensor pollicis longus. The transplant has thus completely reduplicated the pull of the abductor pollicis brevis. If these three principles are utilized and fulfilled, excellent *opposition will be obtained* regardless of the muscle motor used and whether or not a graft is used to extend the muscle motor This method has been used by me since 1949 and it has given the most consistently good results of any of the methods available.

Bunnell in his numerous contributions, has presented the principles involved and the various methods by which these principles may be fulfilled. He states that the insertion must be on the dorsal ulnar aspect of the proximal phalanx of the base of the thumb. From this insertion the tendon must pass subcutaneously in the direction of the pisiform bone, and it must be superficial to the transverse carpal ligament. The various methods of constructing a loop and the various muscle motors that can be used are well covered in his writings

Ney[4] utilized the palmaris longus as the motor power and the extensor pollicis longus as a graft to prolong the motor He describes the transfer as passing under the volar carpal ligament and then passing subcutaneously across the thenar eminence. I have never used the procedure described and feel that it would have small chance of success if the tendon passed under the volar carpal ligament. This operation has been performed many times when the transfer has been kept superficial to the ligament and has been subcutaneous all the way In selected cases this has given good results.

Royle used the sublimis of the ring finger and passed it through the sheath of the flexor pollicis longus after the method of Steindler This did not have the correct pathway and T C. Thompson[7] modified this procedure and used the sublimis of the ring finger leaving it under the volar carpal ligament but bringing the tendon subcutaneously across the thenar eminence and inserting the two slips of the tendon into the thumb one distal to the metacarpophalangeal joint and the other proximal to it. This gave much better results, but tends to duplicate the action of the superficial head of the short flexor of the thumb. This modification of the Royle procedure, in my experience works best in patients with poliomyelitis who show marked relaxation of all structures and in whom there is a need for strong flexion and less rotation.

I have been using a method which fulfills the principles mentioned earlier Littler[8] suggested that the tendon transfer for opposition be inserted into the tendon of the abductor pollicis brevis since this muscle was the all-important muscle of the thenar eminence, according to Duchenne. When *this was tried in difficult cases, it did not give* a satisfactory degree of rotation and deviation of the phalanx of the metacarpal, nor did it give any power to aid in extension of the distal joint of the thumb. After doing some cadaver experiments, I found that the best restoration of full opposition could be obtained by a single tendon transfer if the pull of the transferred tendon duplicated the lines of pull of the abductor pollicis brevis and inserted into the long extensor near the interphalangeal joint of the thumb.

The muscle motors in order of preference are sublimis of the ring finger any other sublimis available, palmaris longus, extensor ulnaris, extensor carpi radialis longus flexor carpi ulnaris, and brachioradialis.

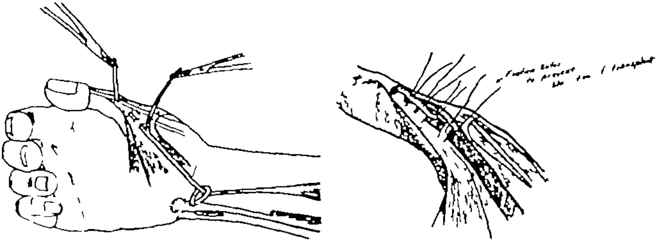
Three skin incisions are used (Fig 62) one on the flexor side of the forearm just proximal to the pisiform and over the flexor carpi ulnaris, the second on the mid lateral side of the proximal inter

A. B.

Fig 62. A, Skin incisions for exposure of the thumb and flexor ulnaris. B, Skin incisions showing lateral approach to finger for removal of sublimis.

phalangeal joint of the ring finger and the third a gently curving incision over the metacarpophalangeal joint on the radial side of the thumb. If the sublimis of the ring finger is used as a muscle motor the tendon is withdrawn from the finger and palm by traction above the wrist and passed subcutaneously across the thenar eminence and brought out into the wound of the thumb One half of the distal two inches of the tendon of the flexor carpi ulnaris is used as a pulley This tendon slip runs from the pisiform around the tendon transfer and back to itself as close to the pisiform as possible. It is felt that a fixed pulley is preferable at all times and that the tendon transfer should not simply be looped around the flexor carpi ulnaris as recommended by Bunnell. The length of the pulley is determined while tension is exerted on the tendon transfer by an assistant using traction, so that the tendon is made to change its angle of approach directly at the point where the normal palmaris longus crosses the flexion crease of the wrist in a wrist that is deviated neither radially nor ulnarward. Tension is then relaxed on the transfer and the pulley is sutured into position as determined by this maneuver

The insertion of the tendon is as shown in Fig 63 A small tunnel is made in the tendon of the abductor pollicis brevis just proximal to its insertion on the proximal phalanx, by two short, parallel incisions elevating the intervening strip of tendon. Usually the sublimis is too large to pass through this small slip of tendon so the two halves of the sub-



A. B.

Fig 63. A, Construction of pulley for opponens transfer and method of inserting sublimis into the flexor poneurosis B, Close-up detail of final suturing of tendon ends to the free ends of the tendon

limis are split proximally for an inch or more and only one half of the tendon is passed through this tunnel The same half of the tendon is then passed through a second small hole in the aponeurosis and brought through the extensor tendon just proximal to the interphalangeal joint This half of the tendon is then turned directly back upon itself and the two halves of the sublimis are overlapped, one half pulling the thumb into opposition and simultaneous extension, and the other half putting tension on the muscle belly The tendon ends are sutured together in such a way that the two tendon ends are buried.

Clawed Fingers

Bunnell's Multiple Sublimis Transplantation. Bunnell's ingenious operation of transplanting multiple slips of sublimis tendons through the lumbrical canals into the aponeurotic expansion has produced excellent results as employed by many surgeons. Bunnell implied that the success of the multiple sublimis transplantations depended upon a bed of soft gliding tissue which allowed the "gliding aponeurosis" to make the transplant both flex the proximal phalanx and extend the distal phalanges. I have found that this tendon transplant gives excellent results for patients with mild cases of claw hand who do not have severe, fixed deformity or who do not have a marked compensatory flexion of the wrist. If there is a fixed deformity or a compensatory hyperflexion of the wrist on attempting to extend the fingers, the sublimis transfer will not be effective. In the first case the fixed deformity can not be overcome by a tendon *transfer* In the second case the flexion of the wrist immediately renders the sublimis transfer ineffective because it does not have sufficient range of motion to extend the interphalangeal joints once the wrist has been flexed therefore the clawing of the fingers cannot be overcome as long as flexion of the wrist is permitted.

The technique for this operation as now used is somewhat different from that described by Bunnell, in that it has not been found necessary to use more than one sublimis tendon for the muscle motor for the Bunnell transplant. The technique employed is to use the sublimis of the long finger splitting it into four strands, passing a strand through the lumbrical canal of each finger and inserting it into the extensor aponeurosis on the radial side of each proximal phalanx. The insertion is done while the proximal phalanges are all flexed to 80 or 90 degrees the middle and distal phalanges are fully extended and the wrist is flexed about 30 degrees to give plenty of slack to the sublimis. Usually the transplants are put in fairly tight with the hand in the above-described position. An excess of 1 to 1½ inches of sublimis is excised from each of the fingers after suturing the transplants into position.

The Bunnell procedure gives the strongest flexor power to the proximal phalanges but should be used only in patients without a marked compensatory flexion deformity of the wrist on attempting to extend the fingers.

Fowler's Extensor Transplantation [3] The technique of the Fowler operation requires the use of the extensor indicis proprius, which is split into two strands, as well as the two slips of the extensor digiti quinti (Fig 64) a slip is passed through each interosseous space anterior to the transverse metacarpal ligament (Fig 65) and is inserted into the aponeurosis. In my experience, I have found it advisable to insert one slip on the radial side of each

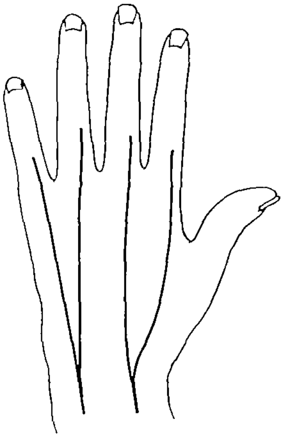


Fig. 64. Fowler extensor transfer showing extensor indicis proprius and extensor digiti quinti each split in half and passed through the interosseous space and brought into the radial side of the proximal phalanx of each finger

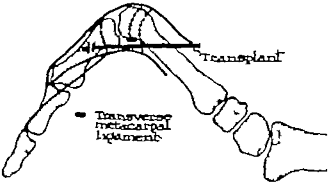


Fig 65. Fowler extensor transplant, lateral view showing transplant passing anterior to transverse metacarpal ligament and being sutured to oblique fibers of the extensor aponeurosis.

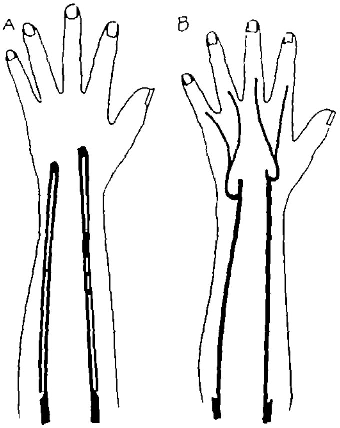


Fig. 66. A, Riordan tenodesis, showing method of using one half of extensor carpi radialis brevis and extensor ulnaris as tendon transfer. B, Each tendon strip is split into two strands and passed through interosseous space as in the Fowler transfer

proximal phalanx in the combined extensor and intrinsic aponeurosis. The original description of the Fowler transplantation specified that the tendon be inserted in the ring and little fingers on the ulnar side, but I now find that all tendons should be inserted onto the radial side of the proximal phalanx of each finger. This will prevent the possibility of an ulnar drift of the finger if the transplant should be put in too tight.

The success of the Fowler transplantation depends on permanently limiting extension of the proximal phalanges at 180 degrees or slightly less. If it does this, and this can be demonstrated at the operating table, then the long extensor is capable of extending the distal two phalanges. In addition to this, it also gives a varying degree of limitation of flexion of the wrist which helps to prevent return of the deformity, for as Bunnell states, "The wrist is the key joint of the hand for muscle balance."

It was originally felt that the Fowler procedure was a tenodesis, but it is now known after many years of observation of postoperative results that this is not true and that active motion of the transfer does occur.

Riordan Tenodesis. Occasionally one will encounter a case of median nerve and ulnar nerve paralysis in which there is not sufficient sublimis strength for a Bunnell multiple sublimis transplantation and in which the extensor muscles are too weak to allow the use of the extensor indicis proprius and extensor digiti quinti. Bunnell, in the second edition of his book, suggested a tenodesis procedure for paralysis of the interossei. In attempting to meet this problem I have devised a method of tenodesis which effectively limits extension of the proximal phalanges and has given excellent results. This was developed in preference to using the bone block procedure of Howard.

In this technique one half of the extensor carpi radialis longus is cut one-third of the distance above the insertion. This half is stripped distally and is left attached to the second metacarpal. One half of the extensor carpi ulnaris is likewise viewed and each of these strands of tendon is split into two slips. (Fig. 66 *A*.) Thus, there are four slips of tendon, two attached to the base of the second metacarpal, and two attached to the base of the fifth metacarpal. One slip is routed through the interosseous space and passed to the radial side of each finger; it is placed anterior to the transverse metacarpal ligament and is inserted into the aponeurosis as in the Fowler transplantation (Fig. 66 *B*.) In each finger the tendon is placed under sufficient tension at the operating table to limit mechanically hyperextension of the proximal phalanges. By experience it has been found safer to put the tendons being transferred under too much tension rather than too little. A tendon which is too tight can be stretched passively to some extent, but one cannot depend upon contracture to shorten a tendon which is too loose.

Fowler Tenodesis.[3] Fowler has described a tenodesis which is essentially the same as that just described but has the further advantage of adding a semiactive motor power to the tenodesis principles (Fig. 67). Instead of having a tendon run from the base of the metacarpal anterior to the transverse metacarpal ligament and then into the aponeurosis as described above, he has taken two long tendon grafts, suturing one end into the aponeurosis as described above, passing this tendon anterior to the transverse metacarpal ligament through the interosseous space, and then passing the tendon through a small hole made in the dorsal carpal ligament. This long tendon graft is then doubled back and passed through the next metacarpal space anterior to the transverse metacarpal ligament and sutured into the radial side of the aponeurosis of the ad

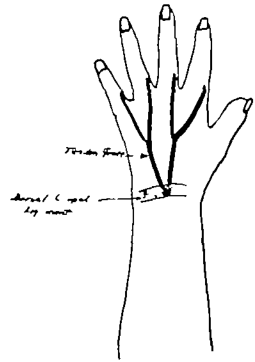


Fig. 67. Fowler tenodesis. Same principle as the Fowler extensor transplant except that this is a tenodesis with the tendons being looped through the dorsal carpal ligament.

jacent finger This means that two long tendon grafts are necessary and these are usually taken from the foot This tenodesis is also put in tight and is sutured into position with the wrist in about 30 degrees of dorsiflexion and the metacarpophalangeal joints in about 80 degrees of flexion with the inter phalangeal joints extended. Since Fowler has de scribed this method, I have used it on a number of occasions and now feel that it gives superior re sults to the tenodesis described previously

New Method. In an effort to find an improved method of getting better extension of the clawed fingers and overcoming the marked compensatory hyperflexion of the wrist which many old untreated cases will show I have developed a different method of transfer (Fig 68)

In most of these old untreated cases with severe clawing and marked hyperflexion of the wrist, the Bunnell transfer is not a good one because it is rendered ineffective each time the wrist is flexed. It was observed in patients with more severe de formities that the flexor carpi radialis was power ful and usually strongly overactive in flexing the wrist as the patient attempted finger extension. It was decided to use this as a motor power move it to the dorsum of the arm and wrist, extend it or prolong it with four tendon grafts, and insert the grafts identically as in the Fowler extensor transplant de scribed above. This would do several things needed. It would weaken the too powerful wrist flexion, me chanically prevent too much wrist flexion and give an intrinsic muscle replacement to each finger It had an added advantage of needing no re-education in so far as function was concerned. Since the wrist flexors act synergistically with normal finger ex tension the flexor carpi radialis automatically contracts when the patient attempts to extend his fingers. This, therefore gives a strong flexor action on the proximal phalanges and a simultaneous extensor ac tion of the middle and distal phalanges. The flexion of the proximal phalanges actually gives the long ex tensor a better mechanical advantage so they also, act in a stronger manner in extending the distal and middle phalanges. The four tendon grafts can be taken from the toes but I usually prefer to use the tendon of the brachioradialis muscle for the tendon graft. The distal end of the brachioradialis tendon is of about the same diameter as the tendon of the flexor carpi radialis, and the proximal end flattens out into a broad band of tendon structure about ¾ to 1 inch in width if it is stripped off the muscle belly carefully This broad band of tendon can then be split into four strands for a distance of about 3 or 4 inches, which is usually sufficient to allow the necessary four tailed tendon graft to go through the interosseous space and through the lumbrical canal of the radial side of the index long ring and little fingers. The single end of this tendon is then sutured end to-end to the transferred flexor carpi radialis on the dorsum of the forearm.

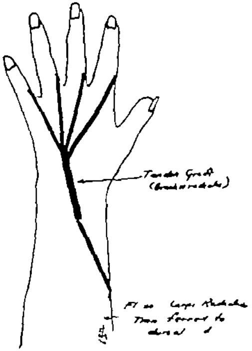


FIG. 68. Riordan transfer showing flexor carpi radialis transferred to dorsal side of the forearm as motor power being extended by a four tailed tendon graft and inserted as in the method of Fowler

RADIAL NERVE PARALYSIS

In a paralysis of the radial nerve in which there is no hope of return of the nerve-muscle function, transfers of the wrist flexors usually can supply a satisfactory range of finger and wrist extension to restore function to the hand.

The functions which should be restored in a high radial nerve paralysis are wrist extension, extension of the proximal phalanges, extension of the thumb and abduction of the thumb. If the flexor carpi radialis, palmaris longus, and flexor carpi ulnaris muscles are present and functioning and if there is intact function of the intrinsic muscles of the thumb and fingers then satisfactory restoration can be obtained by the following transfer (Fig 69)

Extension of the wrist is regained by transferring the insertion of the pronator teres into the extensor carpi radialis longus tendon at mid forearm level The flexor carpi ulnaris is transferred around the ulnar border of the forearm and inserted into the extensor digitorum communis and extensor digiti quinti at the tendon just proximal to the dorsal carpal ligament. The palmaris longus is brought around the radial side of the forearm and sutured into the extensor pollicis longus tendon, which is first cut from the muscle belly withdrawn from around Lister's tubercle and then transferred in a straight line following the direction of the extensor pollicis brevis and abductor pollicis longus. This will give a combined extension of the distal phalanx of the thumb and proximal phalanx of the thumb at the same time that it abducts this first metacarpal.

Adduction of the thumb is done by the normal, functioning adductor of the thumb Only if there

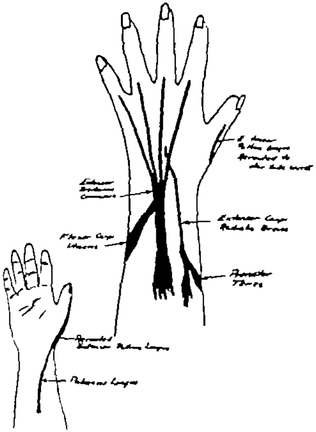


Fig 69. Standard transfer for radial nerve paralysis, with pronator teres being transferred into extensor carpi radialis brevis, flexor ulnaris bei g transferred into extensor digitorum communis, and palmaris longus being transferred l to rerouted extensor pollicis longus

is an ulnar nerve paralysis present is the palmaris longus transferred into the extensor pollicis longus without rerouting it In this case the range of extension obtained is not so good, but it does give some simultaneous extension and adduction which is necessary in this latter case

Only in very unusual cases in which there are other lesions present does the author feel that fusion of the wrist is essential in restoring extension of the fingers and thumb It is felt that the wrist motion aids in extending the fingers and is of more use to the patient than a greater range of extension of the fingers and a stiff wrist would be.

SUMMARY

1 The typical clawhand deformity is caused by the nonfunctioning of interossei and lumbricales, resulting from median nerve and ulnar nerve involvement, regardless of the etiology Function of the long flexors and extensors is still present, and the resulting imbalance gradually causes the deformity to develop.

2. The concepts of Duchenne Bunnell, and Fowler with regard to finger extension and function of the long extensors and interossei and lumbricales explain how these muscles act synergistically to extend the distal two phalanges.

3. The anatomy of the extensor mechanism of the thumb and the fingers has been presented briefly and illustrated.

4 The more useful methods for restoration of opposition of the thumb, including a modified Ney procedure a Bunnell, a Royle Thompson, and a Riordan, have been discussed.

5 Four methods of overcoming clawed fingers—a Bunnell multiple sublimis transplantation, Fowler's extension transplantation Riordan's tenodesis, and Fowler's tenodesis—have been presented.

In addition a new method, previously unreported, of an active transfer similar to a Fowler extensor transplantation but using a wrist flexor as motor power and a four tailed tendon graft has been described.

6. The best method for restoration of wrist and finger extension in high radial nerve paralysis has also been presented.

7 It should be obvious that great care must be exercised in selecting the proper procedure in each case and that the surgeon must have an adequate knowledge of anatomy and the principles involved.

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PART THREE

THE FOOT

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TREATMENT OF CLUBFOOT

Given an opportunity to become old friends with a sufficient number of congenital deformities of the feet, we find that the plain fact of their contrary nature becomes both evident and discouraging

Some of us have devoted a great deal of time and thought to what I have called problem feet—feet that have carried a goodly share of their original deformity into late infancy and early childhood. In so doing they have acquired an increased resistance against correction. Their whole structure has become more strongly molded into the attitude of varus and equinus with the bones and joints adapting themselves in accordance to natural laws of growth.

It is not at all surprising that these older feet, for the most part, are much less willing to respond to the corrective forces which are so effective in early infancy

I do not imply that a perfect score could result even from the application of an ideal treatment program, but I am convinced that we who treat these early deformities are responsible for a large proportion of the later and much more perplexing problems.

There appears to be more or less universal agreement that the earlier one starts correction of congenital foot deformities, the better The reasons are so obvious simple and rational that they deny a difference of opinion.

Unfortunately there seems to be no similar agreement as to the standards of correction how far one should go to obtain these standards, or how long it is necessary to keep them in effect.

And therein lies the largest contribution of problem feet within the group of simple or grade 1 clubfeet—the equinovarus deformities occurring without the presence of any other recognizable congenital anomaly

In order to reduce the number of avoidable problem feet it is necessary to recognize these so-called, but misnamed, "simple" deformities as adversaries worthy of a carefully planned, long-term campaign it is necessary to recognize that they require meticulous attention to detail in their care and it is necessary to recognize that progressive and reasonably rapid correction should take place The same reasons as those for beginning correction early apply to achieving complete correction as early as possible

Correction must be pushed until it is complete. Denis Browne says to push the foot around forcefully and with haste because an infant has little to object with, and a short memory about the experience.

Transformation of the deformity into a normal-appearing foot is only the beginning Too often at this stage the surgeon is so pleased and the parents are so grateful, that without further treatment the foot is encased in an expensive clubfoot shoe, where it pursues an inevitable return toward the original situation. Correction is not attained until the foot goes into full, easy and complete valgus and calcaneus, and the evertor and dorsal flexor muscles are taking their rightful place in leg muscle activity Clinical correction must be verified by corresponding skeletal relationships in the roentgenograms.

Assuming that these requirements have been met

and the subject is 6 months of age, the surgeon has fulfilled about one fourteenth of his responsibility on a chronological basis. He must remember that in all clubfeet, there exists a common denominator of profound proportions, a persistent tendency toward recurrence. They can do and will exert this prerogative for a long period of time at least seven years. It is true that this tendency depreciates with each succeeding year that satisfactory and complete correction is maintained nevertheless, it remains a potent factor always in the background ready to take over at the first sign of complacency

Worse than complacency in the treatment of true clubfeet is the fear of overcorrection or production of permanent excessive valgus. The production of valgus, as I have stated before is a prime requisite in the initial phase of treatment. Just as important is the desirability of maintaining a comfortable margin of valgus until the child has reached the first or second grade in school. By that time, or possibly before the patient will have become intolerant of the crossbar shoe splint, worn at night. Such a splint is one of the best resources we have for combating recurrence.

Permanent excessive valgus does occur but it happens very rarely Its infinitesimal ratio to under correction and its overwhelming advantages as compared with undercorrection easily convince us that no apology is needed when this is produced. I am talking about true clubfoot—not a metatarsus varus.

It will be impossible to cover all aspects of treatment in the allotted time. I will first outline a treatment program as applied early to a case of talipes equinovarus of the usual type and the scheme of follow through in these instances. Success can result only from the concept that the one dominant characteristic of clubfeet is their almost unconquerable tendency toward recurrence We must base their attack on this concept

The usual type of clubfoot is unassociated with other congenital deformities. It may involve one or both feet. There are other varieties appearing as part of more profound congenital disturbances, such as arthrogryposis or spina bifida and still others of neuromyogenic origin or due to osseous defects. The importance of these additional types lies in the recognition of their more serious and profound proportions and their resistance and unsatisfactory response to any form of treatment, including surgery

Treatment should be instituted as soon after birth as possible Because of my own long experience in utilizing plaster of Paris correction boots, it i custom to employ them in the beginning and tinue until I have changed the elements of varu forefoot adduction to a reasonably neutral a ment. At this point, a crossbar kicking spli utilized. I have found it expedient to use plaste the initial attack upon the deformity because it time and avoids the difficulties and complicatio strapping small, markedly resistant feet to the plates. It also avoids the necessity for frec changes and adjustments.

A neutral foot is not difficult to strap efficient the splint, and the basic strapping will, as a last three weeks with weekly visits for reinforcer The Denis Browne or kicking splint has prov most ingenious device for overcoming all elemer the deformity often in a surprisingly short time dimensions are important.

The foot plate should fit the outline of the quite accurately and the front end should ex to the ends of the toes. The toes must be incl in the strapping to neutralize the long flexor mu which are protagonists in the deformity The must be strapped to the plate by carefully pl adhesive straps, holding the foot in as much corrected attitude as possible as each strap is fi anchored to the skin or underlying adhesive. openings or windows in the strapping are left covered throughout the foot, ankle or leg area. cotton flannel bandage is smoothly applied to c the entire adhesive foundation, while again the is held in as much correction as possible. This s both to enforce good adhesion of the tape to the and also as a much-needed protective outer cc ing

The length of the crossbar is critical six in from the centers of attachments to the foot pl being correct for most infants. A bar that is too fails to deliver the proper leverage.

Starting with a foot that corrects to a neutral titude the foot plate is attached at the first appl tion at approximately a right angle to the bar bar is flat and without any bend or curve unless deformity is a unilateral one. For unilateral formities, a varus bend must always be placed the end attached to the uninvolved foot to prev kicking the normal side into excessive valgus. At end of one week usually 10 to 15 degrees abduc of the foot on the bar will be tolerated As soor possible a mild valgus bend is placed in the l centrally for bilateral deformities and only at affected end in unilateral cases.

On successive weekly visits for reinforcement or restrapping one makes sure that the feet stay tight and aligned with the foot plates and that the heels have not pulled free and up from good contact with the heel portion of the splint.

The best skin protection is afforded by painting the feet and legs and all areas to be covered by adhesive with gentian violet 4 per cent in 10 per cent alcohol, as recommended by Dr Harry Blunden of Los Angeles. If this is used, recesses because of skin irritation will not be necessary Interruption for this reason may be disastrous. Placement of the swivel attachment on the foot plate is important this should be beneath the heel and not anterior to it

The foot plate is moved progressively into increased abduction until it finally lies parallel to the bar The valgus bend is gradually increased at the same time. The exact amount of change is difficult to define and will of necessity depend upon the individual deformity and upon just how rapidly the foot will tolerate change

The strap-on splint is continued for several weeks after one has achieved full clinical overcorrection. Roentgenograms are then made and if they demonstrate satisfactory skeletal correction the strap-on splint is replaced with a shoe splint. The same splint may be utilized by riveting the foot plates to high topped, stiff-soled shoes, fitted as accurately as possible as to size. It usually is easier to find full-lace or surgical shoes in the small sizes, and they are of some advantage, as the feet usually retain some puffiness for a time after removal of the strapping

It is not necessary to employ highly corrective, or clubfoot, shoes. In fact, they are likely to be too stiff and unyielding The shoe splint is worn twenty three hours a day which allows for bathing and adequate skin hygiene. The twenty three hour period is gradually reduced in accord with the individual problem. This will depend upon the original degree and resistance of the deformity the ease and length of time needed for correction, and most importantly on the continuing signs of satisfactory and reassuring overcorrection.

The parents are carefully instructed in passive stretching exercises, to be carried out at least twice daily and the patient, as well as the parents instructed in active eversion and dorsal flexion exercises as soon as his understanding permits. Roller skating and ballet lessons are encouraged at an appropriate age After full correction has been obtained and the transfer to shoe splint made recheck examinations are carried out at weekly intervals for several weeks. Then increasing intervals occur between visits depending on reassuring evidence of continuing easy and complete correction As a rule, patients are examined each three to four months until the age of 3 years and after that, each six months. Even for the most satisfactory feet splint wearing at night is made a cardinal principle and continued as long as possible.

We have earlier mentioned the problem foot. A certain percentage of problem feet will always confront the orthopaedic surgeon whose experience brings him into contact with a large number of congenital deformities, for the following reasons (1) There are feet of an inherent variety and pattern which will fail to respond to reasonably diligent and thorough treatment and which never become, by proper standards, adequately corrected. (2) There are feet that have been neglected somewhere along the line and thus have failed to reach adequate correction during the age range when conservative measures are sufficient (3) There are feet for which the application of conservative treatment would require so much additional time with a questionable outlook for success, that it is not practical.

With increased understanding of the morbid anatomy of clubfeet gained by operating upon greater numbers of problem feet, we have come to appreciate more fully the disturbed tarsal relationships, as visualized in the x ray interpretation of the element of talipes varus. We have also learned that in these problem feet there exists a situation parallel to that in the operative treatment of resistant dislocation of the hips, a disturbance of anatomical relationships that would reasonably defy any external method of manipulation and stretching

Operations designed to divide, strip free or remove the contracted ligaments and associated structures on the medial and plantar aspects of the foot have been used rather widely in resistant or persistent varus deformities. It has been our experience that the commonly used procedures are often inadequate to fulfill the desired standards of correction In addition, we have observed that an indiscriminate attack upon the deformity particularly the stripping off of contracted soft parts from immature bone structures, has at times resulted in a stiff foot which too often became more contracted and resistantly deformed than before operation.

THE RELEASE OPERATION

Our release operation developed from the concept that the basic resistance of the deformity to

Fig 70. Deformity in the right foot prior to operation.

correction is to be found at the pivotal point of subtalar motion and is due to the intimate attachment between the talus and the calcaneus, principally the interosseus ligament. In addition to this basic resistance it became plain that all structures on the contracted side of the foot enter importantly into the resistance to correction and that unless all this contraction and tight resistance are released, it is a waste of time to employ surgery

This operation is not the answer to all persistent or resistant deformities, but when used with consideration of the indications and contraindications, it can be expected to effect worth while improvement

Indications for the release operation are as follows (1) failure to obtain the desired standard of correction by adequate conservative treatment (Fig 70) (2) a pattern of persistent or recurrent tendency to lose ground once gained, substantiated by roentgenograms showing a loss of satisfactory correction (3) inadequate correction in a child no longer an infant, for whom the length of time and the requirements of prolonged conservative treatment would prove a burden to all concerned and in whom the continued presence of deformity will result in irreversible structural alteration of the tarsal relationships and (4) clubfeet of neurogenic or fibrodysplastic origin, when conservative measures have proved inadequate and further correction must be attained for weight-bearing purposes, with or without a brace In this type of deformity however the results of release are much less satisfactory and eventual stabilization at an appropriate age will probably be necessary

Contraindications for the release operation are as follows (1) a foot that is used in functional varus but corrects well to passive manipulation and on x-ray examination shows acceptable correction (2) a child who is too young or too old (in this respect, the size of the foot and the x ray evidence of bone and joint differentiation prove helpful) the operation usually being carried out in patients over 2 and under 6 years of age (3) a foot in which the structural changes and alterations of tarsal relationships *will prevent realignment, even though a thorough release* is carried out (such a foot should be treated conservatively until the age of subtalar arthrodesis) and (4) correction of residual forefoot varus or adduction only

The optimum age for medial release is 3½ to 5½ years.

Technique

Operative Procedure A pneumatic tourniquet is utilized after application of an Esmarch bandage from the toes to the mid thigh to ensure a bloodless field. This is of extreme importance. Dissection is carried out with great care to prevent damage to the tarsal and articular cartilage.

Incision Exposure of the medial side of the foot and ankle is provided by an incision which extends from 2½ inches above the medial malleolus, along the posterior border of the tibia curving forward

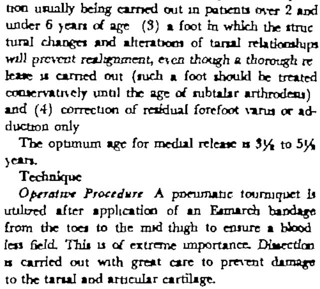

Fig 71 The medial release operation. Incision through *skin and subcutaneous tissues*. It extends from well above and behind the medial malleolus, down round the malleolar tip, then forward over the subtalar joint and deltoid ligament, and ends at the insertion of the anterior tibial tendon.

Fig 72. Anterior and posterior skin and subcutaneous tissue flaps are retracted to expose the deltoid ligament and the talonavicular joint. The posterior tibial nerve artery and vein have been retracted posteriorly and inferiorly. Tendon sheaths of the tibialis posterior, the flexor digitorum longus, and the flexor hallucis longus have not as yet been opened.

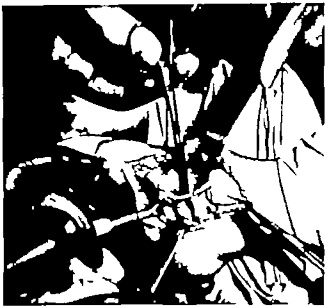

Fig. 73. Tendon of the tibialis posterior is shown divided. Tendons of the flexor digitorum longus and the flexor hallucis longus have been freed from their sheaths and are retracted with the nerve and vascular bundles. The three tendon sheaths have been excised. A complete capsulotomy of the subtalar joint has been carried out and this joint is being pried apart for complete division of the interosseus ligament. After division of this ligament and a complete capsulotomy of the talonavicular joint, it is possible to realign the head of the talus with the navicular bone.

Fig 74. Incision closed by interrupted subcutaneous and skin sutures. The only deep repair is suture of the tendon of the tibialis posterior in a lengthened position.

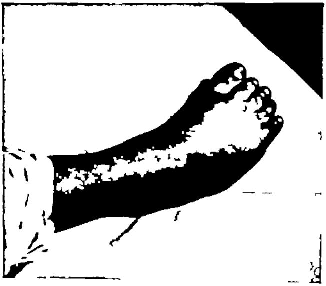

Fig 75. Gravity posture of the foot prior to incision.

Fig 76. Gravity posture of the foot after closure of incision.

Fig 77 Postoperative plaster The attitude should be one of as much correction as the skin closure will tolerate.

Fig. 78. Preoperative and postoperative roentgenograms showing change in skeletal relationships and correction of the arus.

Fig. 79 Right foot three years following medial release operation.

at the level of the subtalar joint, then upward, terminating just distal to the insertion of the anterior tibial tendon (Fig 71)

Subcutaneous Dissection The anterior and posterior skin flaps are developed to include the entire layer of subcutaneous fat, which is usually substantial. The posterior and inferior flap is dissected carefully until the vascular bundle of the posterior tibial artery and vein is located in the leg part of the incision These structures are carefully dissected free from well up behind the malleolus to the point of entrance into the sole of the foot. The small anterior branches from these vessels are identified and ligated The tibial nerve is encountered in close approximation to the vein and artery and is dissected free in a like manner Frequently the nerve and vascular bundle can be isolated as one structure. These vessels and nerve are then constantly retracted posteriorly and inferiorly completely clearing the principal field of operation.

The anterior fat and skin flap is carefully freed across the tibia, the anterior capsule of the ankle, and the talonavicular joint. The anterior vessels are identified and retracted within this flap.

Muscles and Tendons The superior portion of the origin of the abductor hallucis is freed from its attachment and the fibers displaced downward. The sheath of the posterior tibial muscle is opened

and the tendon completely freed from well up behind the malleolus to its Y shaped insertion. The navicular attachment is excised and the tendon divided by a Z-plasty the tendon ends are covered with moist gauze and clamped out of the field The sheath of the flexor digitorum longus is located posteriorly to the previous muscle opened widely and the tendon removed from the sheath and placed beneath the retractors with the vessels and nerve. Still more posteriorly the tendon of the flexor hallucis longus is similarly removed from its sheath and retracted.

Tendon Sheaths and Ligaments Generous segments of all three tendon sheaths are excised below the level of the tip of the malleolus, preserving some of the fibers of the tibiotalar ligament. This removes an important part of the resistance against eversion of the heel. In excising the sheaths of the toe flexors, the sustentaculum tali is uncovered furnishing a landmark to enter the subtalar joint.

Beginning posteriorly as a combined mass the tibiocalcaneal ligament the thick deltoid ligament, and the plantar calcaneonavicular ligament are dissected free from the tibia, the talus and the calcaneus forward to the insertion at the navicular bone from which they are detached, being careful not to partially excise the cartilaginous make up of the navicular bone Removal of these ligaments exposes the neck and medial border of the talar head.

Capsulotomies Division of Periarticular and Intraarticular Ligaments A complete capsulotomy of the talonavicular joint is carried out across the dorsum of this joint from the medial to the lateral side. Care is taken not to damage the articular surfaces of the talus and navicular bones. The subtalar joint is located and opened, and a complete capsulotomy along its medial border is carried out.

A dull edged pry between the talus and calcaneus is of great assistance at this point and aids in exposing the interosseus ligament which runs transversely across the subtalar joint, binding the calcaneus and talus together in their intimate varus relationship

Division of this ligament produces the most marked release of the deformity and allows the entire foot to be swung outward into abduction beneath the talus The medial subtalar capsulotomy is extended posteriorly entirely across the back of this joint. This can be done safely because the tendons with the vessels and nerves are retracted out of the way

Repair of Tendons and Closure of the Incision At time of closure these factors must be observed

The posterior tibial tendon is sutured with sufficient increased length to accommodate a full correction of the deformity

If too much tension remains within the tendons of the flexor digitorum longus and the flexor hallucis longus in the attitude of full correction they are lengthened in a similar manner to that of the posterior tibial Usually this is not necessary

No deep sutures are employed Interrupted subcutaneous catgut sutures are used to close the fat layer and the skin is closed by interrupted chromic catgut or silk. The chromic sutures in the skin are advantageous if the immediate degree of correction is satisfactory because the dressing then need not be changed until its final removal.

Maximum correction of the deformity as allowed by skin tension at the suture line is important. The corrected attitude is maintained by a circular plaster of Paris bandage applied over an ample skin covering of sheet wadding The plaster usually extends to the knee in some instances, it may be desirable to extend it above the flexed knee, to the mid thigh.

Postoperative Care

If full correction is not obtained at the time of operation, additional correction is added at the end of ten to twelve days, by changing the plaster or wedging the original cast. Postoperative fixation is maintained for eight weeks.

If in addition to correction of a varus element, correction of an equinus element is necessary this is accomplished by lengthening of the tendo achillis and capsulotomy of the posterior ankle joint, at the end of six to eight weeks from the medial release operation.

After removal of the plaster a cross-bar shoe splint is employed for part time maintenance of the corrected attitude active exercises are encouraged, and weight bearing activities are allowed just as soon as the child can initiate them.

Shoe corrections consist of an outer heel shank and sole wedge of ⅛ inch for daytime wear

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THE SURGICAL RELEASE OF FIBROUS TISSUE STRUCTURES RESISTING CORRECTION OF CONGENITAL CLUBFOOT AND METATARSUS VARUS

Before describing special surgical procedures in the treatment of clubfoot and metatarsus varus, it should be clearly understood that what we say here is not to be interpreted as lessening the importance of adherence to the fundamentals of conservative treatment, or that we advocate operative procedures as an easy short-cut to circumvent the more tedious but essential details in the proper management of these deformities. On the contrary when we fail to attain a good correction of clubfoot or metatarsus varus by nonsurgical means in a child who comes under our control early during the first few months of life we should search our minds for deficiencies in our own treatment and not too readily seek escape from responsibility by placing the blame upon factors said to be beyond our control

Be that as it may it is not uncommon in our own patients or consultation practice to be faced with situations of residual or resistant deformity in older children, for whom the usual methods of conservative treatment will no longer suffice, and when some operative procedure is required. We have in mind an intermediate-age group of children, between 3 and 7 years old with a persistence of one or more of the components of clubfoot deformity or the deformity commonly known as metatarsus varus. At this age correction is quite difficult, and it becomes increasingly so as the child grows older Repeated manipulations or wedging of plaster casts are not only ineffective for these older children but also produce still more fibrosis and joint stiffness. Complete section of the resistant joint capsules, ligaments, or other fibrous tissue bands which resist correction is much more effective and causes less reaction to trauma. The operative release of soft tissue structures resisting correction frequently permits immediate restoration of normal bone relationships and alignment of the foot.

The deformity of clubfoot and metatarsus varus in the newborn infant is chiefly the result of a shortness or contracture of soft tissues, causing a faulty alignment or apposition of the bone and joint relationships, rather than a primary distortion of the shapes of the bones hence the importance of attaining correction of the deformity before secondary adaptive bone deformity takes place and while the deformity can still be corrected by conservative means which do not injure these young growing bones. Tendon transference will not correct fixed deformity *Joints must be mobilized beforehand.* Tendon transference may prevent recurrence of deformity which has already been corrected, as when recurrence is the result of a persisting inequality of muscle balance.

With these general considerations in mind, we shall describe an operative procedure which has

been quite helpful in mobilizing the fore part of the foot for correction of resistant adduction deformity in older children with clubfoot or metatarsus varus and also our procedure for the release of soft tissue resistance for correction of inversion of the foot or adduction of the heel. For convenience we term the former operation "anterior capsulotomies," and the latter "medial capsulotomies" or a medial release. We shall not describe the widely known posterior release which consists of lengthening the Achilles tendon and capsulotomy of the ankle joint for correction of the equinus component of clubfoot. The necessity for correction of inversion before attempting to bring the foot up into dorsiflexion must always be borne in mind.

ANTERIOR CAPSULOTOMIES

The resemblance of the deformity of the fore part of the foot in clubfoot and in metatarsus varus is so close that the same principles and methods of treatment apply to each condition. Correction of these deformities in children over 3 years of age is frequently so difficult that wedge resection of bone or osteotomies of the metatarsals have been thought to be necessary. We have now found that most of these deformities in older children, those up to and including 6 or 7 years of age, can still be corrected by less radical treatment which does not injure bone or disturb bone growth.

At the tarsometatarsal articulations, the bases of the five metatarsals are firmly bound to the three cuneiforms and to the cuboid by strong dorsal, interosseus, and plantar ligaments. The bases of the lateral four metatarsals articulate with each other and are bound together by strong interosseus ligaments which pass between the nonarticular portions of the basal parts of the metatarsals. The operation (Fig. 80) consists in mobilizing these joints by freely cutting all tarsometatarsal and intermetatarsal ligaments and joint capsules. The approach is through an incision across the dorsum of the foot, which provides an excellent exposure of all of these articulations and permits a good view of the cuneiform bones when cutting the ligaments of these articulations and may also contribute to mobilization of the fore part of the foot. The transverse incision has regard for the creases of the skin, and has the advantage that the entire tarsometatarsal joint is seen. There have been no complications in wound healing. Comprehensive data of the results following this operation were published in 1958.

Operative Technique. With a pneumatic tourniquet in place, a curved incision is made across the dorsum of the foot beginning at the medial side of the first tarsometatarsal joint and extending to the base of the fifth metatarsal bone. The incision may be extended proximally at the medial side to expose the cuneonavicular articulation so that these ligaments may be cut if they also appear to offer resistance to correction. The skin flaps are retracted upward and downward exposing the deep fascia covering the tarsometatarsal articulations. The tibialis anterior tendon is identified and protected, and attention is paid to any abnormality of its insertion. During the course of the procedure which follows, care is taken not to cut the extensor tendons. In younger children, one may not readily identify the middle three tarsometatarsal joints, but with patience it is not difficult.

A longitudinal incision is made through the deep fascia over the first tarsometatarsal joint. This fascia is retracted, exposing the dorsal ligaments. The dorsal and interosseus ligaments and joint capsule are cut freely by a deep incision carried around the base of the first metatarsal, taking care not to cut the tibialis anterior tendon at its insertion. The joint is then flexed sufficiently so that the knife may be inserted through it to cut the capsule and ligaments at the plantar aspect. Although this joint is now mobilized, it is clear that this procedure alone is insufficient to attain appreciable correction of deformity of the fore part of the foot. Another longitudinal incision is next made through the deep fascia over the interval between the bases of the second and third metatarsals. The articulations of both these bones can be exposed by retracting the deep fascia. A deep incision is made, encircling the base of each of these metatarsals, and the joint capsules and the dorsal, interosseus, and intermetatarsal ligaments of these articulations are freely cut through. Similarly a third longitudinal incision is made through the deep fascia over the interval between the bases of the fourth and fifth metatarsals, and the corresponding ligaments and capsules of these articulations are cut. Finally while traction is upon all metatarsals and the tarsometatarsal joints are flexed the knife is introduced through each joint to cut the capsules and ligaments transversely at the plantar aspects. The knife may also be circled around the cuneiform bones, but this does not contribute much more to the mobilization of the fore part of the foot.

After the ligaments and joint capsules of the intermetatarsal and tarsometatarsal articulations are thoroughly cut through, the lateral four metatarsal bones

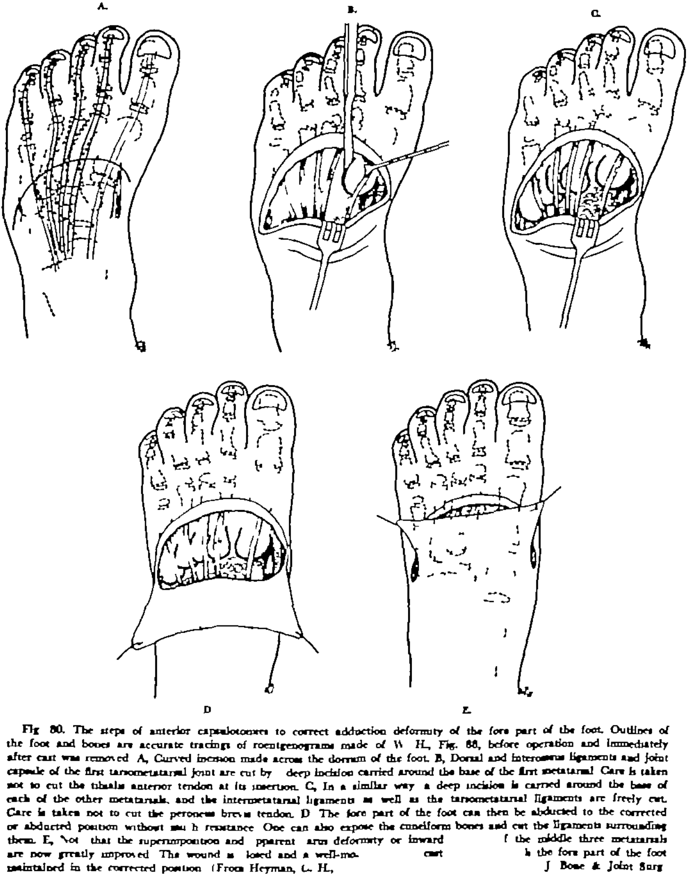
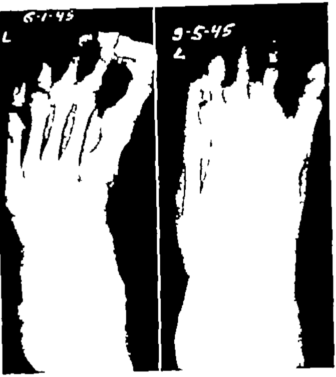
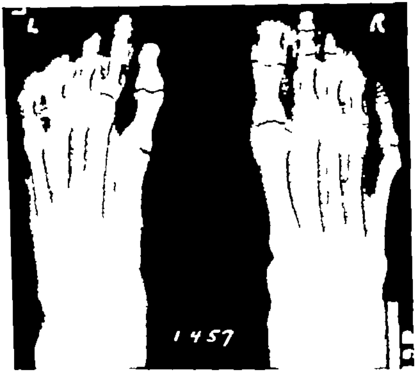


Fig 80. The steps of anterior capsulotomies to correct adduction deformity of the fore part of the foot. Outlines of the foot and bones are accurate tracings of roentgenograms made of W H., Fig. 88, before operation and immediately after cast was removed A, Curved incision made across the dorsum of the foot. B, Dorsal and interosseus ligaments and joint capsule of the first tarsometatarsal joint are cut by deep incision carried around the base of the first metatarsal Care is taken not to cut the tibialis anterior tendon at its insertion. C, In a similar way a deep incision is carried around the base of each of the other metatarsals, and the intermetatarsal ligaments as well as the tarsometatarsal ligaments are freely cut. Care is taken not to cut the peroneus brevis tendon. D The fore part of the foot can then be abducted to the corrected or abducted position without much resistance One can also expose the cuneiform bones and cut the ligaments surrounding them. E, Not that the superimposition and pparent arus deformity or inward f the middle three metatarsals are now greatly improved The wound is losed and a well-mo cast h the fore part of the foot maintained in the corrected position (From Heyman, C. H., J Bone & Joint Surg 40-A: 299 1958)



A. B.



C.

Fig. 81 A-D. J B. The resistant inversion component of clubfoot deformity had previously been corrected by medial capsulotomies when the patient was 4 years old. Anterior capsulotomies and a plaster cast for ten weeks corrected the residual adduction or varus of the fore part of the foot. A, Roentgenogram made June 1 1945 when the patient was 5½ years old, showing residual adduction of the fore part of the left foot. B, Roentgenogram made Sept 5 1945 when cast was removed, ten weeks after anterior capsulotomies. C, Roentgenogram of both feet Jan. 4 1957 eleven years seven months after operation. (From Heyman C. H Herndon, C. H., and Strong, J M.: J Bone & Joint Surg 40-A: 299 1958.)

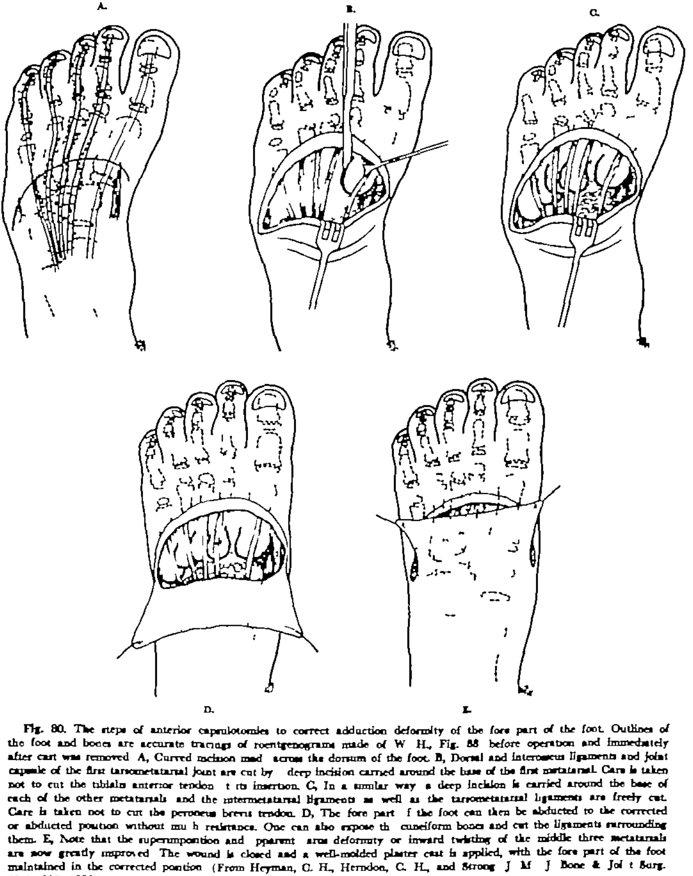
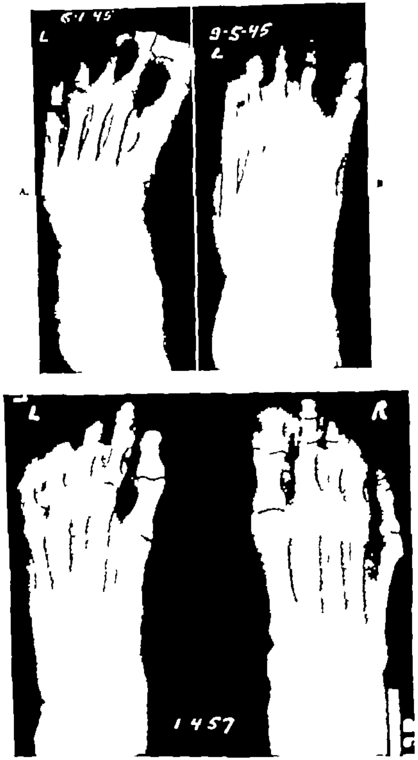


Fig. 80. The steps of anterior capsulotomies to correct adduction deformity of the fore part of the foot. Outlines of the foot and bones are accurate tracings of roentgenograms made of W. H., Fig. 88, before operation and immediately after cast was removed. A, Curved incision made across the dorsum of the foot. B, Dorsal and interosseus ligaments and joint capsule of the first tarsometatarsal joint are cut by deep incision carried around the base of the first metatarsal. Care is taken not to cut the tibialis anterior tendon at its insertion. C, In a similar way a deep incision is carried around the base of each of the other metatarsals and the intermetatarsal ligaments as well as the tarsometatarsal ligaments are freely cut. Care is taken not to cut the peroneus brevis tendon. D, The fore part of the foot can then be abducted to the corrected or abducted position without much resistance. One can also expose the cuneiform bones and cut the ligaments surrounding them. E, Note that the superimposition and apparent varus deformity or inward twisting of the middle three metatarsals are now greatly improved. The wound is closed and a well-molded plaster cast is applied, with the fore part of the foot maintained in the corrected position. (From Heyman, C. H., Herndon, C. H., and Strong, J. M.: J. Bone & Joint Surg. 40-A: 299, 1958.)



A.

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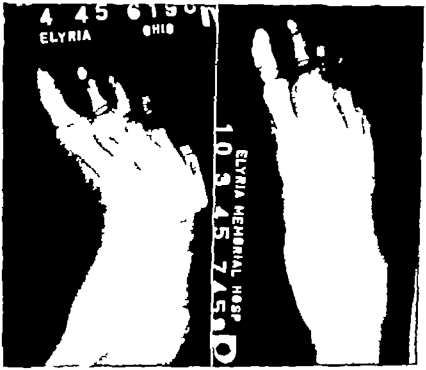
Fig. 81 A-D J B. The resistant inversion component of clubfoot deformity had previously been corrected by medial capsulotomies when th patient was 4 years old. Anterior capsulotomies and a plaster cast for ten weeks orrected the residual adduction or arus of the fore part of the foot. A, Roentgenogram made June 1 1945 when the patient was 5½ years old, showing residual adduction of the fore part of the left foot. B, Roentgenogram made Sept. 5 1945 when cast was removed, ten weeks after anterior capsulotomies C, Roentgenogram of both feet J n. 4 1957 eleven years seven months after operation. (From Heyman, C. H., Herndon, C. H and Strong J. M. J Bone & Joint Surg 40-A. 299 1958.)

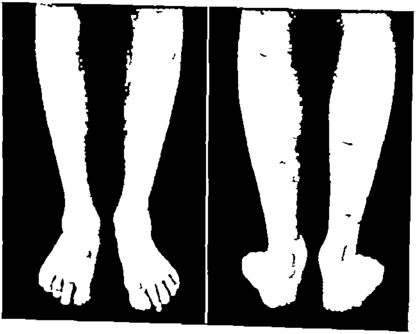
Fig. 81 (cont'd) D Photographs made Jan. 4 1957 (From Heyman, C. H Herndon, C. H., and Strong J M. J Bone & Joint Surg. 48-A: 299 1958.)



A. B.

Fig. 82, A-D. J T A case of severe congenital metatarsus varus in a child 5 years old who had received no treatment. Correction of the deformity was attained by anterior capsulotomies and maintenance of correction in a plaster cast for seven weeks. A, Roentgenogram made May 5 1945 when the boy was 5 years old, showing severe metatarsus varus of the right foot. B, Roentgenogram made Oct. 3 1945 when cast was removed, seven weeks after anterior capsulotomies. (From Heyman, C. H., Herndon, C. H., and Strong J M.: J Bone & Joint Surg. 48-A: 299 1958.)

C.



D.

Fig. 82 (cont'd) C, Roentgenogram of both feet made Dec. 21 1956 eleven years four months after operation. D Photographs made Dec. 21 1956. (From Heyman, C. H Herndon, C. H and Strong J M J Bone & Joint Surg 40-A: 299 1958.)

A

B

Fig. 83, A-D T M. Resistant inversion deformity of the hind part of the foot and adduction deformity of the fore part of the foot in bilateral clubfoot under conservative treatment for two years The deformity of each foot was corrected by a combined medial and anterior capsulotomies operation and maintenance of correction in plaster cast for three months. A, Roentgenogram of both feet made Jan 15 1946 when the patient was 2½ years old. B, Roentgenograms of both feet made May 2 1946 three months after combined medial and anterior capsulotomies. (From Heyman, C H Herndon, C. H., and Strong J M J Bone & Joint Surg 40-A: 299 1958)

C.

D.

Fig. 83 (cont'd) C, Roentgenogram of both feet made Jan. 4 1957 eleven years after operation. D Photographs made Jan. 4 1957 (From Heyman, C. H Herndon, C. H., and Strong J M J Bone & Joint Surg 40-A: 299 1958.)

A.

C.

Fig 84. F D Resistant adduction deformity in case of clubfoot in child 5 years old, corrected by a combination of anterior capsulotomies and transposition of th tibialis anticus tendon. The postoperative cast was worn six weeks A, Roentgenogram made of the right foot May 14 1946 Anterior capsulotomies and transposition of insertion of the tibialis anterior tendon to lateral border of the foot were done Nov 3 1948 when the child was 5½ years old. B, Roentgenogram made of both feet Nov 16 1956, eight years after operation. C, Photographs made Nov 16, 1956 (From Heyman, C. H Herndon, C. H, and Strong, J M J Bone & Joint Surg 40-A: 299 1958.)

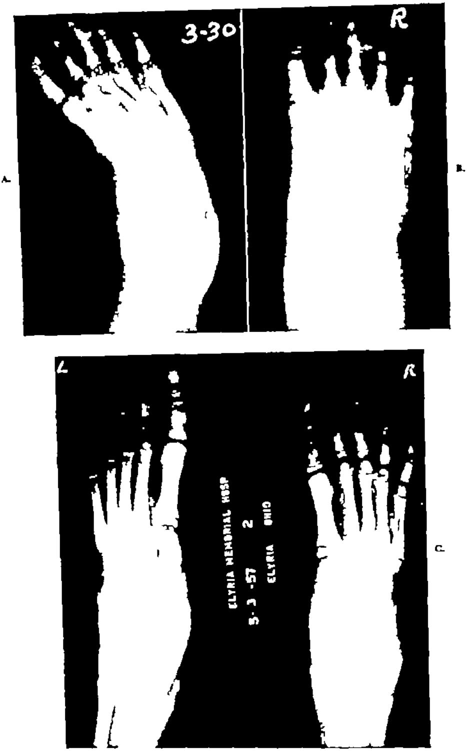


Fig. 83, A-D D L Resistant adduction deformity of the fore part of the foot in a case of clubfoot corrected by anterior capsulotomies and maintenance of correction in plaster cast for fourteen weeks. A, Roentgenogram of the right foot made March 30 1953 when the patient was 4 years old B, Roentgenogram made Dec. 3 1954 seven months after medial capsulotomies t correct inversion deformity of the right foot, and three months after anterior capsulotomies to correct adduction deformity of the fore part of the foot. C, Roentgenogram of both feet made May 3 1957 three and one-half years after these operations.

Fig. 85 (cont'd) D Photographs made May 5 1957

will glide upon one another and the fore part of the foot will swing outward at the tarsometatarsal joint without much resistance. If the child is young enough, or if bone deformity has not progressed to a serious degree the adduction deformity can be over corrected. The skin is then closed and a well molded plaster cast is applied with the fore part of the foot held in as much abduction as possible with care taken that the heel is not everted

Two weeks after the operation, the cast is changed in order that the foot may be inspected. The correction may not have been as thorough as was thought, and a little more stretching of the fore part of the foot into further abduction may be desirable. As a rule, however this is not necessary It is recommended that the foot be maintained in the corrected position in a walking cast for at least three months. The steps of the operation are depicted in the drawings of Fig 80 Some preoperative roentgenograms and postoperative results are illustrated in Figs 81 to 88.

MEDIAL CAPSULOTOMIES

The procedures for the correction of resistant inversion or adduction of the heel in clubfoot are commonly known as the Ober or Brockman operations. Our method for the correction of deformity of the hind part of the foot is basically that of the Ober operation which consists of release of the deltoid ligament and joint capsules at the medial side of the subtalar joint and sustentaculum and the talonavicular ligaments. This is to permit eversion of the heel and restoration of the medial displacement of the navicular bone to a normal position in relationship to the head of the talus. With the accumulation of experience we have modified this technique. In several cases the result had been an overcorrection of the heel from a position of inversion to a rather severe degree of eversion or ankle valgus. This was particularly likely to occur when tenotomy of a taut tibialis posterior tendon was performed in addition to transection of the deltoid ligament at its attachment to the tibia Eversion of the heel, after transection of the deltoid ligament opposite the ankle joint and stripping it downward, leaves a gap of unsupporting fibrous tissue at the medial side of the ankle joint. This is more pronounced after tenotomy of the tibialis posterior tendon. Our procedure now consists more of an advancement of the origin of the deltoid ligament, rather than a transection which leaves a strong fascial support at the medial aspect of the ankle joint. We also do not release the pull of the tibialis posterior tendon unless it is quite obvious that this taut structure is seriously resisting correction of inversion. It should then be lengthened and sutured to preserve its function rather than to sacrifice it. Attention to these details has materially lessened the number of unsatisfactory results caused by overcorrection. The tendon and function of the tibialis posterior should also be preserved for possible use in the future, as for transference between the tibia and fibula to the dorso-

Fig. 86. R. C. A case of clubfoot with residual adduction deformity of th fore part of the foot in a child 4 years old. Th deformity was corrected by anterior capsulotomies and maintenance of correction in plaster cast for three months. A Roentgenogram of th right foot made Oct. 4 1949 Medial capsulotomies operation was performed Oct. 5 1949 and anterior capsulotomies operation on May 5 1950. B, Roentgenogram of both feet Nov 16, 1956 six and one-half years after anterior capsulotomies operation. C, Photographs made Nov 16 1956.

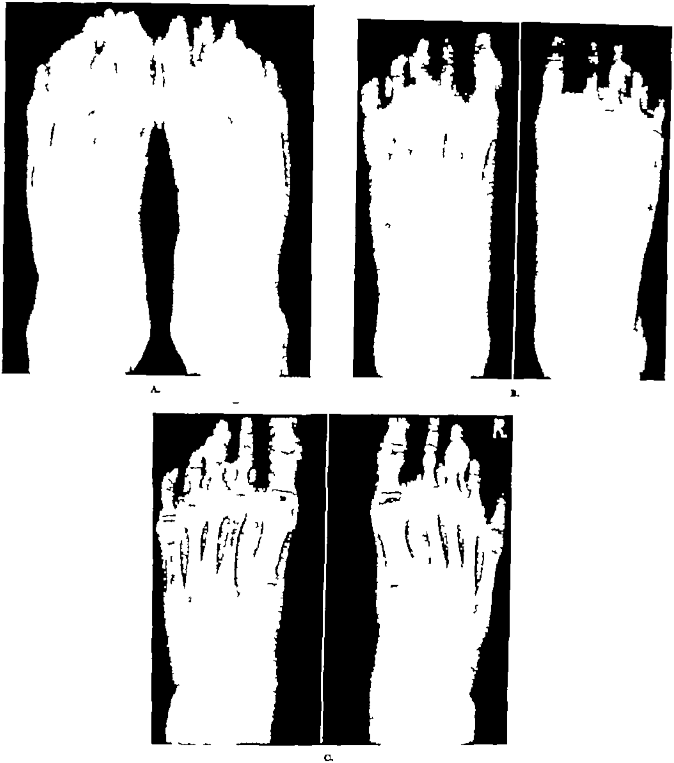
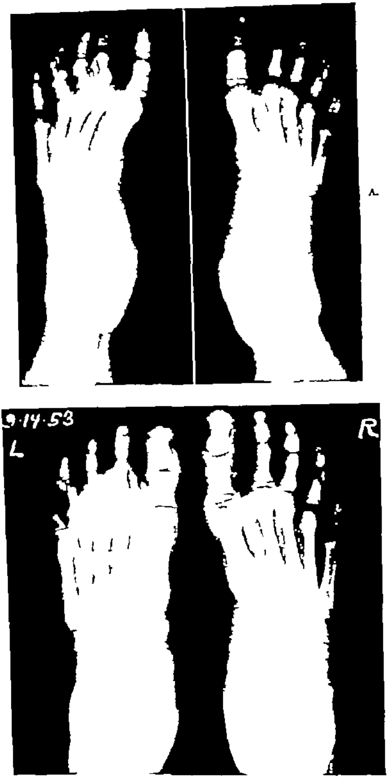


Fig. 87 J Y Bilateral clubfoot with residual deformity of the fore part of the feet. Anterior capsulotomies operations were performed in December 1952 when the patient was 5 years old A, Roentgenogram of both feet made Nov 16, 1951 when the patient was $3\frac{1}{6}$ years old There was residual adduction deformity of the fore part of the feet in clubfoot. B, Roentgenogram of both feet made March 4 1953 when postoperative casts were removed C, Roentgenogram of both feet made Nov 6, 1953 one year after the operation.



A.

B.

Fig. 88. W. H. Uncorrected deformity of the fore part of the foot in a case of clubfoot. A, Roentgenogram of both feet made July 10, 1953, showing adduction deformity of the left foot when the boy was 5 years old. B, Roentgenogram of both feet made Sept. 14, 1953, immediately after postoperative cast was removed, nine weeks after anterior capsulotomies. Note that the superimposition and apparent arcs or inward twisting of the middle three metatarsals are no longer present. (From Heyman, C. H., Herndon, C. H., and Strong, J. M.: J. Bone & Joint Surg. 48-A: 299, 1958.)

lateral aspect of the foot. The steps of medial capsulotomies or medial release are depicted in the drawings of Fig 89

Particular attention is paid to the tibionavicular ligament and strong fibrous tissue band connecting *the lower margin of the tibia to the navicular bone.* In addition to the talonavicular ligament, this resistant structure holds the navicular bone at a position of medial displacement on the head of the talus. This tissue is completely excised. The stripping of

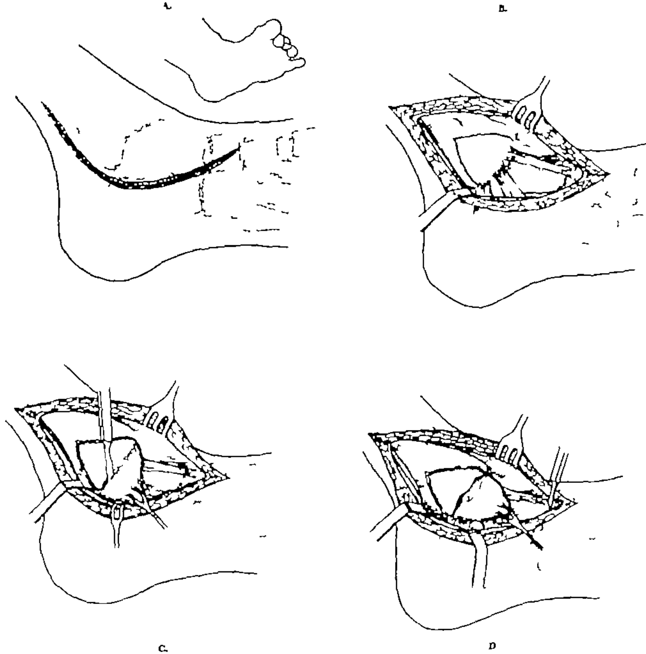
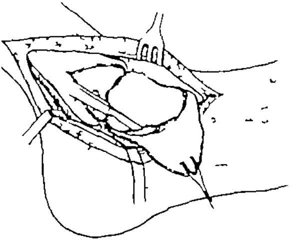
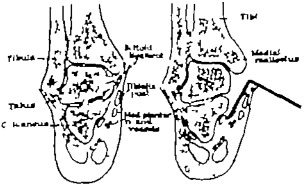


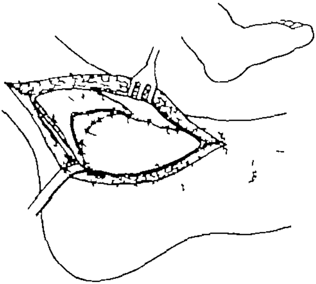
Fig. 89 A-G. Steps in operation to correct adduction or inversion deformity of hind part of foot in clubfoot. This is the medial capsulotomies, or release operation. A, Curved incision extending from behind medial aspect of lower end of tibia to navicular bone B, The skin flap is undermined and reflected anteriorly An inverted V-like incision is made through deep fascia above the ankle joint, exposing and protecting the tibialis posterior tendon. C and D, The tongue of deep fascia is reflected downward to the ankle joint. The attachment of the deltoid ligament to the tibia is cut by deep incision carried round the internal malleolus, extending into th nkle joint

E



F





G

Fig. 89 (cont'd) E, The anterior limb of the incision through deep fascia is then continued downward to the navicular bone, and the talonavicular ligament and joint capsule of the talonavicular joint are cut transversely Anterior and medial bands of the deltoid ligament and other soft tissues are peeled away from the talus and calcaneus, exposing the subtalar joint and sustentaculum. The dense fibrous tissue band, extending from the internal malleolus to the navicular bone is completely excised. The foot is then manipulated into eversion, rocking the calcaneus outward and replacing the navicula bone in line with the head of the talus. The incision may be continued distally to expose the inner cuneiform bone if necessary F Drawing of coronal section through the ankle joint showing attachments of the deltoid ligament and subperiosteal dissection of this ligament and other soft tissue structures from th internal malleolus and the medial sides of the talus nd calcaneus. The tendons, vessels, and nerve are protected by a retractor G, With manipulation of th foot into eversion, the tongue of deep fascia ad ances downward, where it is sutured to the periosteum of th tibia. This flap extends cross the ankle joint and protects against excessive ankle valgus afterward The tendon of the tibialis posterior is not sectioned. It is lengthened and carefully sutured only when it is obvious that it seriously obstructs correction. (F redrawn from Gray H: Anatomy of the Human Body Philadelphia 1954 Lea & Febiger)

ligaments and soft tissue away from the talus and calcaneus proceeds downward, exposing the subtalar and talonavicular joints. Injury to the tendons and blood vessels is avoided by subperiosteal dissection and retraction. We also attempt to cut the interosseus talocalcaneal ligament by inserting the knife deeply between the talus and calcaneus. If we thought it were important to see and clearly define this ligament, we would do so through another short incision at the lateral side of the foot and expose it through the sinus tarsi.

This operation, the medial release is ordinarily used in children between the ages of 3 and 6 years. At this time the surfaces of the talus, calcaneus and navicular are still soft and cartilaginous. The process of stripping the ligaments and joint capsules from the medial aspects of these bones is done by sharp dissection with a knife which carefully skins or peels the soft tissue from the bones. It cannot be well done with a blunt periosteal elevator because of the likelihood of making an artificial dissection extending into the cartilaginous substance of the bones. A periosteal elevator may be inserted deeply afterward to pry away other resistant bands of soft tissue The foot is then manipulated into an everted position. The tongue of tissue composed of the flap of deep fascia, formed before cutting the deltoid ligament, is seen to glide distally but still covers the medial side of the ankle joint If it is obvious that inversion deformity has been corrected, one may then use force in dorsiflexing the ankle or even lengthen the Achilles tendon if necessary after exposing it by retraction of the posterior limb of the incision.

The postoperative plaster cast is applied from the toes to the hip with the knee flexed 90 degrees. One must avoid too much overcorrection, which this operation may allow It is also important to avoid excessive stretching of the blood vessels, which may cause postoperative deficiency in circulation. Two weeks after the operation, the cast is changed. If more correction is desirable the foot is manipulated for this purpose. A walking cast extending from the toes to the knee is then worn for about eight weeks. We have not found any brace afterward to be effective in preventing either recurrence or overcorrection. Failure to obtain a good correction must be attributed to ineffectiveness of the operation itself or to irreversible adaptive deformity of the bones.

Medial capsulotomies or release will not correct adduction deformity of the fore part of the foot which occurs at the tarsometatarsal and intermetatarsal articulations, nor will anterior capsulotomies correct adduction of the heel or inversion deformity at the hind part of the foot with medial displacement of the navicular bone on the head of the talus. Occasionally these operations are done separately at different stages. In such cases we correct the deformity at the hind part of the foot by medial capsulotomies before the final stage of correction of any residual adduction of the fore part of the foot by anterior capsulotomies Some of the patients in the illustrations had both procedures. We have found that anterior capsulotomies have been particularly effective for the correction of resistant or untreated metatarsus varus in older children, up to 8 years of age, without the necessity of osteotomies or bone or joint resections.

REFERENCE

1 Heyman, C. H., Herndon C H., and Strong J M., Mobilization of the Tarsometatarsal and Intermetatarsal Joints for the Correction of Resistant Adduction of the Fore Part of the Foot in Congenital Club-Foot or Congenital Metatarsus Varus, J Bone & Joint Surg 40-A: 299 1958

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THE DIAGNOSIS AND TREATMENT OF CONGENITAL CONVEX PES VALGUS OR VERTICAL TALUS

DIAGNOSIS

The time allotted to this subject does not permit us to do more than call it to your attention by illustrative roentgenograms, describe the diagnostic characteristics, and briefly suggest methods of treatment. For a full discussion of this deformity and a comprehensive bibliography attention is called to an article by Lamy and Weissman in 1939 and for the surgical treatment to articles by Hark in 1950 and Osmond-Clarke[3] in 1956. Our opinions are based upon approximately twenty five cases during the past thirty years.

This relatively rare deformity has been described under different terms by many writers, chiefly in the foreign languages but the distinguishing characteristics which differentiate it from common flatfoot or calcaneovalgus are not widely known. The incidence is probably more frequent than is commonly thought. Terms such as "vertical talus" or "plantar flexed talus" single out only one component or roentgenological appearance of the deformity and may fail to distinguish it from severe degrees of common flatfoot or paralytic valgus in which the tarsal bones and longitudinal arch are lowered and the foot is pronated and abducted. In these latter conditions, the talus may be in an oblique position on weight bearing roentgenograms, leading to a false interpretation of a true luxation or vertical talus. In young children, before ossification of the navicular bone has progressed to be distinguished in the roentgenogram a complete luxation of the talonavicular joint may not be clearly demonstrated. Other aspects of the deformity clinical as well as roentgenological, must be taken into consideration for diagnosis in the questionable case. Hence we prefer the term "congenital convex pes valgus," proposed by Lamy and Weissman, as more descriptive and less likely to cause confusion. In contrast to common relaxed flat foot this condition is frequently unilateral with no abnormality at the other foot.

The clinical appearance of congenital convex pes valgus in very young children or babies may be similar to that of congenital calcaneovalgus, but there are important differences. The fore part of the foot is abducted and tilts upward at the mediotarsal joint. The sole is not only flat but is also convex on dorsiflexion of the foot. The foot cannot be inverted. There is a bony prominence of the head of the talus at the plantar aspect of the foot, which cannot be reduced by pressure or manipulation. Although the peroneal and extensor tendons may stand out taut and resist passive inversion, one can feel a bone obstruction to inversion of the foot. *The foot is not in* a position of excessive calcaneus at the ankle joint, as in calcaneovalgus. The Achilles tendon is tight and the calcaneus is tilted downward in plantar flexion. When the foot is being pushed into dorsiflexion, the deformity at the mediotarsal joints causes a con-

A.

B.

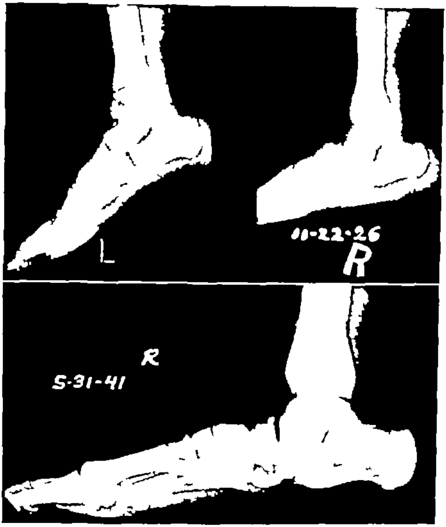


Fig 90. R. V A, Lateral roentgenograms of both feet of boy 8 years old. There is a unilateral convex pes valgus with the talus in a vertical position, and the navicular bone is articulating with the superior surface of the neck. The calcaneus is plantar flexed. B, The same patient when 23 years old. There is complete luxation of the talonavicular joint, and the navicular bone has become deformed Although there was a severe rigid flatfoot, the patient was not complaining of any disabling symptoms. No treatment was necessary

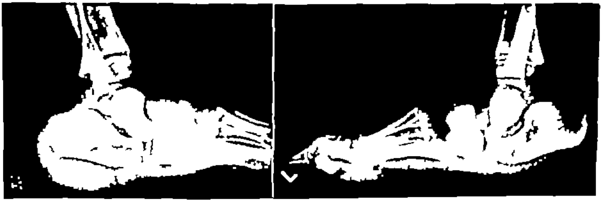


Fig. 91 U C Lateral roentgenograms of both feet, showing bilateral deformity The talus points directly downward in line with the tibia. Note that the calcaneus is in plantar flexion and the fore part of the foot is bent upward, causing a convexity at the sole or rocker bottom foot. Although the navicular bone is not visible in the roentgenogram, it must be in apposition to the superior surface of the talus.

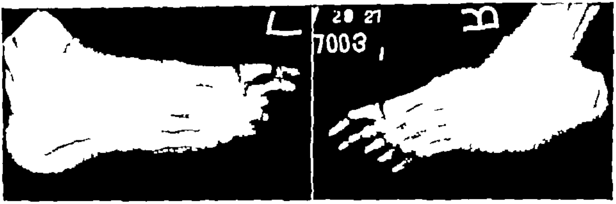


Fig. 92. J. P. Roentgenograms of both feet, showing unilateral deformity. The talus of the right foot is underdeveloped and is in a vertical position. The calcaneus is tilted downward, and there is a convexity at the sole. The navicular bone articulates with the neck of the talus.

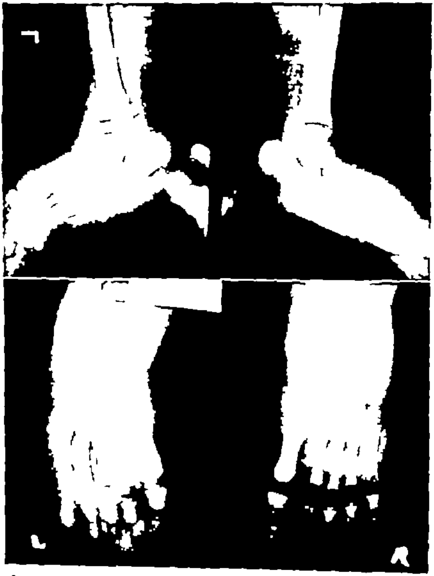


Fig. 93. L. G. Lateral and anteroposterior roentgenograms of bilateral vertical tali in a baby. The calcaneus is tilted downward, and the sole is convex. The talus is directed inward, particularly in the right foot.

vexity or rocker-bottom appearance at the sole. The deformity in infants is more likely to be confused with congenital metatarsus valgus which may possibly be a lesser degree of the same condition. The more severe degrees of the deformity in infants present no difficulty in diagnosis.

The roentgenological characteristics are illustrated in Figs. 90 to 98. The most striking appearance is that of the talus which is rotated or pointing downward *to a vertical position. There is complete luxation* of the talonavicular joint, with the navicular bone articulating with the superior surface of the neck of the talus. This distinguishes the deformity from severe degrees of pronated feet or flatfeet in which the talus may be in an oblique position but the joint surfaces remain in contact. The calcaneus is tilted downward into equinus, sometimes to a severe degree, and is generally underdeveloped or has a convexity at the plantar surface. The fore part of the foot tilts upward. In older patients the navicular bone becomes wedge-shaped. This is probably a secondary adaptive change to the luxation. The anteroposterior roentgenogram shows the talus directed inward. *A study of comparable roentgenograms* during weight bearing is helpful in learning to distinguish a true vertical talus or congenital convex pes valgus from congenital flatfoot or paralytic valgus.

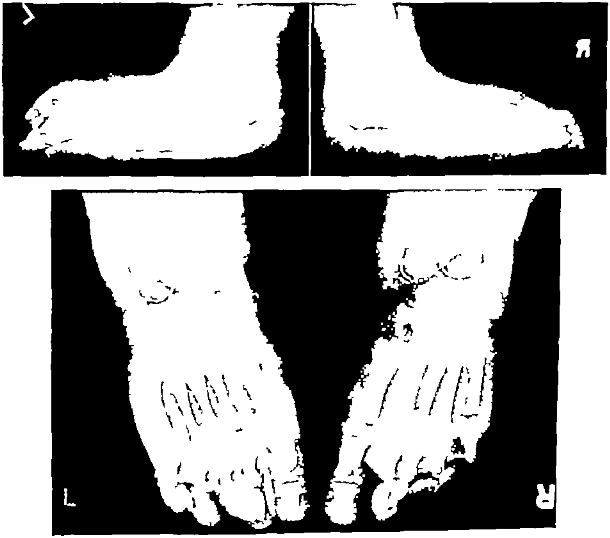


Fig. 94. S K. Lateral and anteroposterior roentgenograms made at 21 months of age, showing bilateral deformity Both feet had been manipulated under anesthesia and casts had been applied with no improvement in the roentgenological appearance. The talus is in a vertical position and is directed inward. The heel is tilted downward to a moderate degree The clinical appearance of the feet had been considerably improved No operation was advised.

TREATMENT

Treatment depends upon the age of the patient and the severity of the deformity In contrast to the case of congenital calcaneovalgus, correction is diffi cult. In babies or very young children manipulation under anesthesia can bring about an improvement in the general appearance of the foot and possibly result in fairly good function without much dis ability but it is unlikely to be successful in reducing the luxation or result in any appreciable improvement in the roentgenological appearance Since the calcaneus is held in plantar flexion by a taut Achilles tendon, manipulation is directed toward stretching the fore part of the foot downward into plantar flexion and inversion to line it up with the hind part of the foot, and toward trying to rotate the talus by pressing the head upward The plaster cast is applied afterward with the foot in equinus and in version Several manipulations and casts may be necessary to accomplish significant improvement.

The patients in Figs. 97 and 98 both had four manipulations and plaster casts, using force over a Lorenz wedge and a Thomas wrench, with no appreciable improvement shown in the roentgenograms.

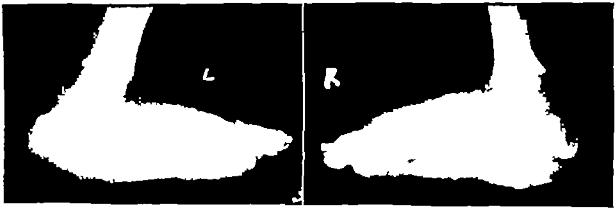
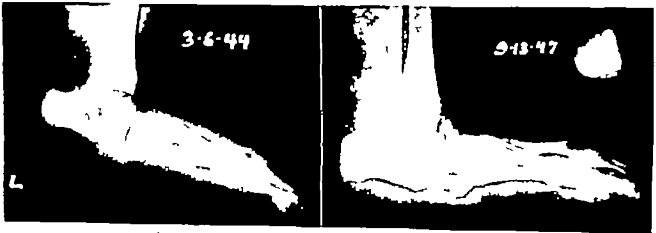
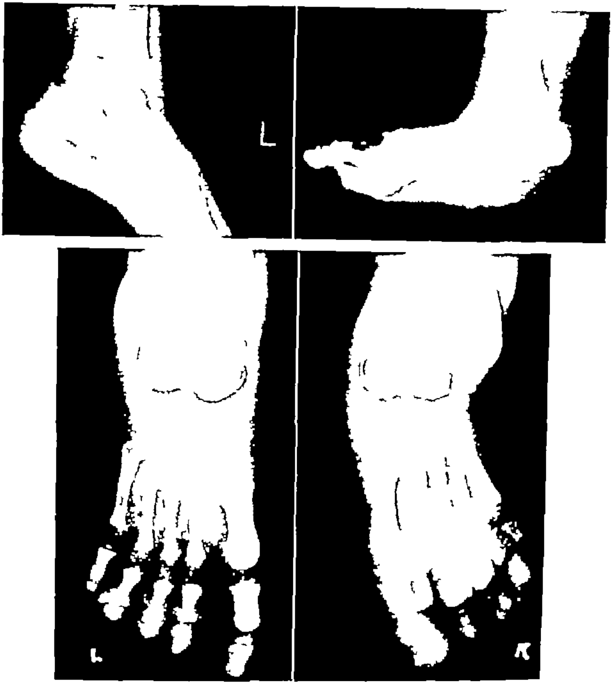


Fig 95. M. F Lateral roentgenograms of bilateral convex pes valgus t the age of 19 months. The fore part of the foot is tilted upward. The child had had many manipulations and casts, beginning at 1 month of age, and there still remained a rigid flatfoot deformity An attempt at open reduction was ad sed but this was not performed. When the child was 4 years old, the head of the talus was excised bilaterally with considerable improvement in ppearance nd function of both feet.



A. B.

Fig 96. J P A, Lateral roentgenogram of a severe deformity in a girl 6 years old. Note the ertical position of the talus, the underdevelopment and downward tilting of the calcaneus, the upward tilting of the fore part of the foot, nd the convexity at the sole. A painful ulcer caused by pressure of the shoe, was present over the prominent head of the talus. The head and neck of the talus were excised, the body of the talus was tilted upward, and a triple arthrodesis was *performed. B, Lateral* roentgenogram showing the result, three years later Although there remained severe, rigid flatfoot, painful disability was relieved.



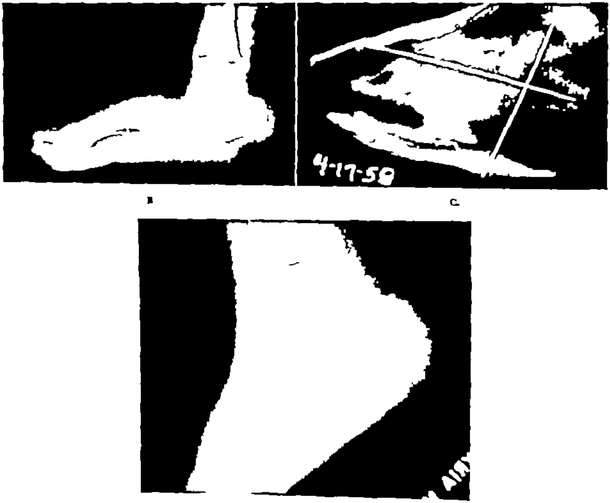
A.

Fig. 97 A-D. J F A severe deformity which could not be corrected by forcible manipulations and plaster casts under anesthesia Correction of the deformity was then attained by the operative procedure described in the text. A, Lateral and anteroposterior roentgenograms made of both feet Oct. 17 1937 before treatment, when the child was 22 months old. There is severe deformity of the right foot. The talus is vertical and directed inward, the calcaneus is tilted downward, the fore part of the foot is tilted upward, and the sole is convex

The deformities still remained sufficiently severe to justify attempts at reduction by open operation In other patients, open reduction was not recommended As a rule we do not believe that restoration of normal bone relationships can be attained by any means other than by open operation, and even by this means it may be quite difficult to obtain and retain Careful selection of patients is required therefore before subjecting these young children to surgery One may obtain satisfactory function without complete correction. The patient whose roentgenogram is shown in Fig 90 never had any complaint other than the unsightly appearance of a flatfoot. No treatment, therefore was necessary and particularly no operation was advised

Our first attempt at open reduction of the deformity was in 1940 This was a case of bilateral deformity in a child 4 years old Manipulations under anesthesia and the use of casts failed to result in any significant improvement in the clinical appearance of the left foot. After section of the ligaments and joint capsules attached to the talus, through incisions on both sides of the foot, the talus could be rotated upward and the valgus deformity overcome. No internal or Kirschner wire fixation was used to maintain reduction. Both clinical and roentgenological results, nine years later in 1949 were excellent Triple arthrodesis was necessary to relieve painful symptoms in the other foot in 1945

The patient whose roentgenogram is shown in

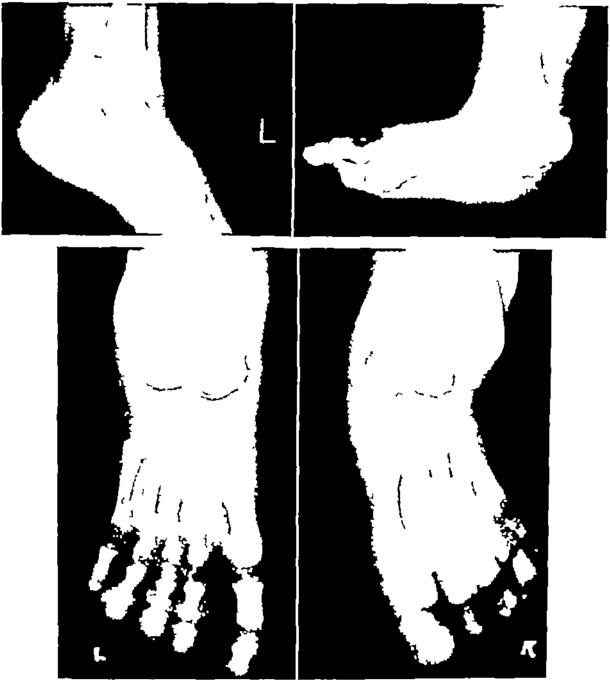


B

C

D.

Fig. 97 (cont d) B, Roentgenogram made April 15 1958 after four attempts at reduction by manipulation while under anesthesia and the use of casts. There was no appreciable improvement. C, Lateral roentgenogram in the plaster cast (April 17 1958) following open reduction and fixation by Kirschner wires. D Roentgenogram made Aug. 13 1958 showing good reduction and alignment of the fore part of the foot with the hind part. The deformity was corrected and there was good motion in the tarsal joints.



A.

Fig. 97 A D. J F A severe deformity which could not be corrected by forcible manipulations and plaster casts under anesthesia. Correction of the deformity was then attained by the operative procedure described in the text A, Lateral and anteroposterior roentgenograms made of both feet Oct 17 1937 before treatment when the child was 22 months old. There is severe deformity of the right foot. The talus is vertical and directed inward, the calcaneus is tilted downward, the fore part of the foot is tilted upward, and the sole is convex.

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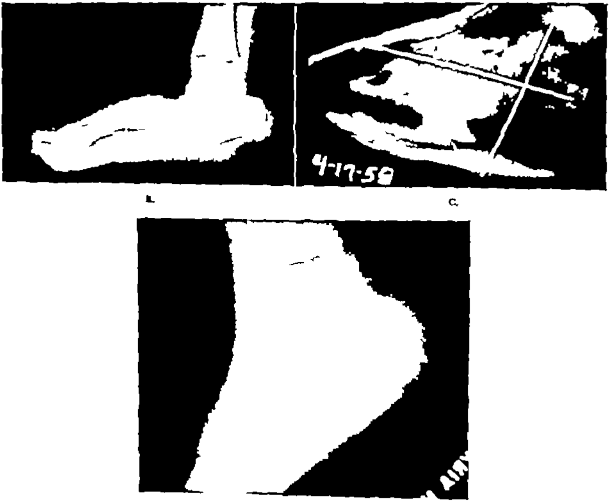
The patient whose roentgenogram is shown in



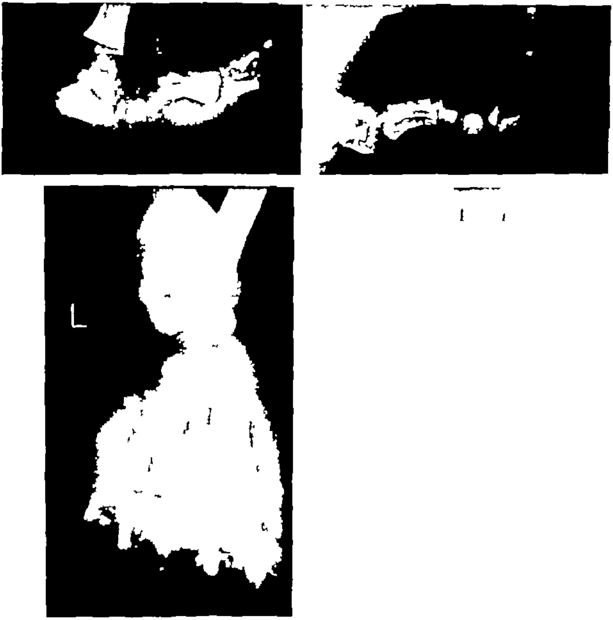
B. C.

D.

Fig 97 (cont d) B, Roentgenogram made April 15 1958 after four attempts t reduction by manipulation while under anesthesia and the use of casts. There was no appreciable improvement. C, Lateral roentgenogram the plaster cast (April 17 1958) following open reduction and fixation by Kirschner wires. D, Roentgenogram made Aug. 13 1958 showing good reduction and alignment of the fore part of the foot with the hind part. The deformity was corrected, and there was good motion I the tarsal joints.

Fig 96 had a severe deformity with a painful ulcer caused by the pressure of the shoe over the bone prominence at the head of the talus. It was quite unlikely that the talus could be rotated upward to reduce the bone prominence in a patient of this age and this was not attempted. The head of the talus was excised to relieve the pressure, and that patient's symptoms were relieved without correcting the severe flatfoot

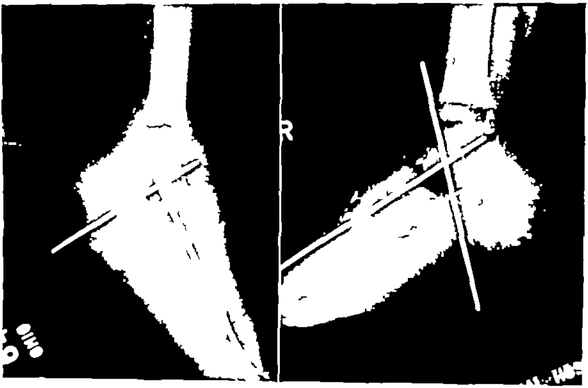
After communicating with Hark, we were encouraged again to attempt open reduction in selected cases of younger children, and to stabilize the reduction by the insertion of Kirschner wires through the navicular bone and calcaneus into the talus. These



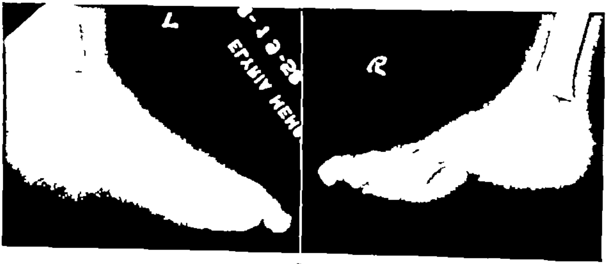
A.

Fig. 98, A-C. J A. A, Lateral and antero
Feb. 25 1938 when the child was 5 months old
fore part of the foot is tilted pward suggestin
plantar flexed, causing ity t the sole
vertical and is direc This patient
wedge and plaster ca anesthesia wit
appearance and witho ment in the cl

wires were incorporated in the postoperative plaster cast. The operation consists of mobilizing the talus by cutting the ligaments and joint capsules of the talonavicular and calcaneocuboid joints. The talus is then rotated upward and the fore part of the foot is manipulated downward to restore alignment with the talus and calcaneus. It may be necessary to lengthen the extensor tendons to do this, but stretching them before operation by manipulations and casts will probably make this unnecessary. To



B.



C.

Fig. 98 (cont'd) B, Lateral roentgenograms made June 18 1958 when postoperative casts were changed. The fore parts of the feet now appear to be in good alignment with the hind parts, and the luxation of the talonavicular joints appears to be reduced. C, Good reduction of the deformity of the left foot, Aug. 19 1958 but reduction of the deformity was not maintained in the right foot. The Achilles tendon had been lengthened at the left foot, but not at the right.

bring the foot upward into dorsiflexion at the ankle joint may require a second-stage operation to lengthen the Achilles tendon.

It is not only difficult to obtain reduction, but it is also difficult to retain it. The bones tend to spring back into their former positions. Osmond-Clarke recommends transfer of the peroneus tertius tendon into the neck of the talus to hold it upward. Hark inserts a Kirschner wire through the navicular bone into the head and neck of the talus. Figs. 97 and 98 are roentgenograms of the Kirschner wires we have introduced to stabilize reduction. Although we have not tried it as yet, it would seem that the Grice procedure of inserting a graft of cortical bone between the anterior process of the calcaneus and the neck of the talus could maintain correction by serving as a bone prop holding the talus rotated upward. An undesirable effect of such a prop, however, would be maintenance of the calcaneus in a downward tilted position. The Grice procedure would not apply before ossification of these bones has progressed sufficiently to secure a firm support and good bony union and probably should not be attempted before the child is 3 years old.

In patients several years of age or older it may either be impossible to attain anatomical reposition by any operation or be unwise to attempt it. In these cases we must be content, therefore, to alleviate disability by some other means, such as excision of the prominent head and neck of the talus when the shoe causes painful pressure at this prominent bone or a remodeling operation and triple arthrodesis to correct deformity. When symptoms are not disabling in older patients and the clinical deformity is not too severe, we do not recommend any surgical treatment.

Our studies of approximately twenty-five patients with congenital convex pes valgus are still in progress. We now believe that this is an entity probably the result of an arrest in fetal development, and not merely an extreme degree of ordinary flatfoot. We hope to have more definite conclusions and to improve our methods of treatment.

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THE ROLE OF SUBTALAR FUSION IN THE TREATMENT OF VALGUS DEFORMITIES OF THE FEET

Stabilization of the subtalar joint by means of bone grafts placed across the tarsal sinus was originally conceived in order to correct severe valgus deformity arising in young children. When the deformity occurred in older patients, it was not so severe and often could be corrected by tendon transplants, either alone or in combination with triple arthrodesis. The most severe valgus deformities developed when there was complete paralysis of the anterior and posterior tibial muscles in a child under 3 years of age. If the peroneal muscles and the triceps surae group were strong the deformity was progressive in spite of the use of arch supports, braces, night casts, exercises, and various reconstructive soft tissue procedures.

If the deformity were not corrected in the young child, the foot became so badly distorted by the age of 10 or 12 years that it was very difficult to restore a satisfactory appearance to the foot by means of triple arthrodesis. In the young child, below 10 years of age triple arthrodesis should be deferred if possible because inhibition of growth of the mid-tarsal bones will occur Since soft tissue surgery had proved inadequate it seemed necessary to consider some means of stabilizing the mid-tarsal region without interfering with growth.

CONSIDERATION OF PATHOMECHANICS

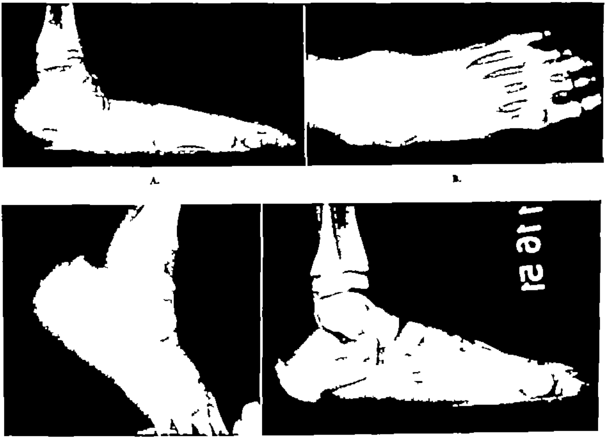
The logic of stabilizing the subtalar joint in order to control the valgus foot can be readily appreciated by studying the dynamics of the foot. The ankle joint (tibiotalar) and the mid tarsal joints combine to make up a universal joint. Through the tibiotalar joint motion occurs only in a vertical plane, producing plantar flexion and dorsiflexion. The motions of eversion and abduction, as well as inversion and adduction, occur through the mid tarsal region and are integrated with the movement of the os calcis in respect to the talus through the subtalar joint. In the normal intact foot, the os calcis moves posteriorly in respect to the talus as it swings out into eversion. Conversely it moves forward as it is inverted or placed in varus. If the ligamentous structures of the mid-tarsal and tarsal region are intact the cuboid, navicular and cuneiform bones move with the os calcis. For practical purposes, it may be assumed that the foot distal to the talus moves as a unit and that the attitude of either pronation or supination is determined by whether the heel is inverted or everted. Thus as the os calcis moves into valgus (eversion) the rest of the foot is abducted, presenting the picture of a pronated foot.

It is true that the position of the talus does change in the varus and the valgus positions, but the position assumed by the talus is a passive one There are no muscles inserted into the talus. In the normal foot and in the varus deformity the talus is in a relatively horizontal position, but in the valgus deformity it assumes a vertical position (Fig 99 *A*) Its position is determined by the

support provided by the os calcis beneath it. As the os calcis is displaced laterally and posteriorly in eversion, there is no support to the head of the talus. It, therefore drops down into equinus. As the foot is inverted, the front of the os calcis moves forward and medially beneath the talus and provides support. If this relationship cannot be obtained then the normal contour of the foot cannot be restored

In the paralytic valgus foot, with paralysis of the anterior and posterior tibial muscles, the dynamic forces producing inversion and adduction are lost. If the peroneal muscles are strong the everting force displaces the os calcis into valgus and the typical pronated foot develops. Should the triceps surae be strong and a contracture of the Achilles tendon develop even more valgus develops as the os calcis is further displaced posteriorly and into valgus.

The control of the paralytic valgus foot is related to several factors. The imbalance of the musculature must be corrected by decreasing the everting force and restoring the inverting strength. In addition to this, some means must be at hand to restore the relationship of the rest of the foot to the talus and to maintain it by fusion of the os calcis to the talus (Fig 99 *C* and *D*) Previous attempts at fusion of the subtalar joint involved resection of the joint. Such procedures were successful in restoring and maintaining the relationship of the os calcis to the talus but, unfortunately disturbed the dynamics of the other mid-tarsal joints. Secondary degenerative changes often developed in the talonavicular and the calcaneocuboid joints. This was particularly true in the growing child, because of the increasing disproportion between the talocalcaneal bone mass and the naviculocuboid structures, as the result of the loss of growth in the subtalar region. Growth of the mid-tarsal bones is appositional in nature, and re



A. B. C D.

Fig. 99 A, Lateral roentgenogram of the left foot, severe valgus, plantar flexed talus. B, Anteroposterior view left foot lateral and posterior displacement of os calcis, abduction of forefoot. C, Lateral roentgenogram showing passive correction of deformity by placing foot in equinus and adduction D Lateral view of right foot for comparison Slight posterior displacement of os calcis and obliteration of tarsal sinus, indicating mild valgus

section of the talocalcaneal articular surfaces destroys this growth potential.

REPORTED EXPERIENCE WITH SUBTALAR FUSION

The placement of bone grafts in the tarsal sinus provides a means of obtaining an immediate mechanical fixation of the joint in the desired position, as well as the basis of subsequent fusion of the joint. Inasmuch as the articular surfaces are not resected further growth will occur without loss in the height of the talocalcaneal bone mass. This, then, was the procedure which was devised and first performed in 1945 on a 5-year-old boy with a paralytic valgus foot following poliomyelitis. This patient was observed for several years, and since the result appeared satisfactory the operation was performed on a larger group of polio patients. The operative technique and a preliminary report was published in 1952[4] and a follow-up on fifty-two patients in 1955[5]. In the latter article the indications, limitations, complications, and end results were discussed. Since the appearance of this article the experiences of other surgeons have been reported in the literature.

At the American Academy of Orthopaedic Surgeons meeting in February of 1956 Westin and Hall presented a preliminary report on their experiences with sixty two stabilizations performed on children between the ages of 3 and 12 years. Included in their series were patients with paralytic pes planus, calcaneovalgus deformity flail feet and severely pronated feet without paralysis. In 1957 Wehsman, Torok, and Kharmosh reported favorable results obtained in a series of thirty cases of paralytic valgus deformities. Malvarez presented a series of eighty seven cases in 1957 in which the fusion was obtained with preserved homogenous bone. There were seventy four excellent results and thirteen failures. The youngest patient was 2 years old and the oldest 6 years. Baker and Dodelin discussed the use of subtalar fusion in the correction of twenty-nine feet with severe valgus deformities occurring in seventeen cerebral palsy patients. The youngest patient in this series was 3 years old and the oldest 15 years. These authors concluded that on the basis of function and cosmetic appearance the results were good to excellent.

In our own experience during the ten-year period from 1946 to 1955 this procedure has been performed on 108 feet. A considerable variety of patients has been included in this series. There are patients with congenital planovalgus feet associated with a plantar flexed talus, valgus deformities associated with spasticity in cerebral palsy valgus feet in spina bifida, paralytic calcaneovalgus, severely pronated feet without paralysis and talocalcaneal coalitions. In older patients, this procedure has also been used with excellent results in treatment of fractures of the os calcis, arthritis of the subtalar joint, and tuberculosis of the subtalar joint.

OPERATIVE TECHNIQUE

The operative technique is quite simple for one who is familiar with the mechanics of the foot. The subtalar joint is exposed through a 2-inch curvilinear incision placed on the lateral aspect of the foot directly over the tarsal sinus. The distal portion of the incision begins at the lateral border of the extensor tendons just a little above the superior edge of the os calcis. The incision is extended posteriorly in the direction of the skin creases to the peroneal tendons and just below the tip of the lateral malleolus. Subcutaneous fat is divided in the line of the skin incision down to the tarsal ligament. The ligament is divided in the direction of its fibers and reflected. The ligament also may be divided parallel to the peroneal tendon sheath at its lower end in order to obtain wider exposure. The ligaments and adipose tissue in the tarsal sinus are completely removed, exposing the talus and the os calcis. The origin of the extensor digiti brevis is dissected free of the superior margin of the os calcis and reflected to allow complete visualization of the subtalar joint. The foot is everted and the movement of the os calcis in respect to the talus is observed, as well as the relationship of the undersurface of the talus to the superior surface of the os calcis. There is great variation in these borders of the tarsal sinus. A few moments spent in study of the configuration and movement of the os calcis as it moves in eversion will allow one to decide the proper position in which to place the graft or grafts. This can be confirmed by selecting an osteotome of the proper width to span the tarsal sinus and placing it between the talus and os calcis so that it blocks eversion of the os calcis. If the osteotome turns in the tarsal sinus and moves with the os calcis, it is improperly placed. The usual position is such that the inferior aspect of the osteotome is in contact with the superior border of the os calcis and is farther forward than the upper edge in contact with the talus (Fig 100). In some instances, this cannot be readily obtained, and the

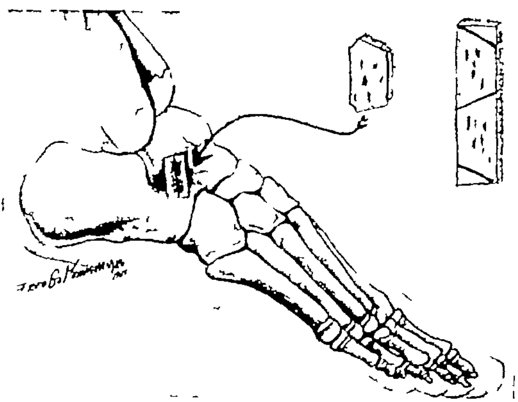


Fig. 100. Insertion of grafts in the tarsal sinus. (From Grice D S J Bone & Joint Surg. 37-A: 246 1955.)

grafts will, of necessity be placed in another position. This should be determined with one or two osteotomes before the bed for the grafts is cut. The essential feature is that the grafts or osteotomes should effectively stabilize the foot and prevent motion of the os calcis in relation to the talus, once they have been put in place. The width of the tarsal sinus is measured and allowances made for the additional length required after the bed for the grafts has been cut in the talus and the os calcis or in some instances, for impaction of the grafts into the talus and os calcis. The graft is obtained from the metaphyseal region of the tibia just below the insertion of the hamstring tendons. The periosteum is divided and reflected exposing the cortical bone. A graft 4.5 to 5 cm. long by 1.5 cm. wide is usually removed. The graft is taken from this area since it has thinner cortical bone and more cancellous bone. It is also more likely to stimulate growth from the adjacent epiphysis, if so desired in a short leg. If growth stimulation is not desirable the bone may be removed from the fibula, the rib, the ilium the opposite tibia (if it is short) and even homogenous preserved bone may be used.

The graft is then cut diagonally across, making two trapezoidal pieces. These are placed together with the cancellous surfaces in contact and are measured up against the tarsal sinus in the approximate position in which they will be placed. Right angle notches are then cut into the undersurfaces of the talus demarcating the widths of the two grafts. A thin sliver of cortex is removed between the two notches. A similar bed is cut into the upper surface of the os calcis. These should be no wider than the thickness of the two grafts so that it will be a tight fit. The grafts are then cut to size. This is done with a narrow rongeur so as to make a serrated edge on each end. This makes the grafts hold better. The foot is then inverted to open up the tarsal sinus, the grafts are placed in position, and the foot brought back to the desired position. The foot should not be left in an overcorrected position, nor should the grafts pry the two bones apart. If either of these things occur the grafts should be made smaller before the joint is closed and the grafts are impacted. In feet with osteoporotic bone the grafts will sink deeply into the substance of the bones if one is not careful. In such feet, do not remove the cortex or cut deep notches for the grafts, but merely allow the grafts to penetrate into the cortical bone on both sides. It is desirable to impact the grafts only once. The more times the grafts are tried the poorer be-

comes the fit, because the mortise tenon feature of the grafts is destroyed as the bed for the grafts becomes distorted.

Once the grafts have been properly placed the foot is stable and cannot be displaced into valgus. If the foot is not stable the grafts must be repositioned. In rare instances, additional fixation with a screw or Kirschner wires may be needed. The tarsal ligament is sutured with No 3-0 silk and No. 5-0 silk sutures are inserted in the skin.

This technique of using two trapezoid-shaped grafts is described because we have found it the simplest and most effective way to produce a mechanical block. It allows greater ease of adjustment as to fit and the degree of correction than other methods. Numerous variations have been tried by us, and many other surgeons have described techniques that they prefer. Whatever method is used, it is essential that the fixation should be secure at the time of operation and that the graft should be under some compression. If the grafts are not securely fixed, they will slip or absorb or both complications will occur. These are the most common technical errors.

Other common errors are undercorrection and overcorrection. If the deformity is not sufficiently corrected, the foot is fused in valgus and the condition is analogous to the fixed valgus position found in congenital talocalcaneal coalition. It would not be surprising to find that such patients develop peroneal spasm—and they do. It is better however to err on the side of a little valgus than a little varus, since the varus deformity appears to increase with growth. One uncommon complication has been absorption of the mid portion of the grafts. This seemed to occur in one instance when bone bank grafts were used and it has been seen when the grafts were too long and pried the joint apart. It should be stated that this list of problems has been assembled through the experience of many individuals who have brought them to our attention. We ourselves have made most of the mistakes along the way—but not all of them!

GENERAL CONSIDERATIONS

One of the most common causes of poor results from this procedure is the failure of the surgeon to recognize that the essential feature is not the fusion of the subtalar joint but the restoration of normal alignment before placing the grafts for fusion. The grafts are used merely to maintain the correction. If the foot is inadequately corrected it will be fused in valgus, and if it is overcorrected there will be a varus deformity. The majority of valgus deformities in young children can be passively corrected without any difficulty. In some instances, soft tissue dissection about the subtalar joint and the talonavicular joint will be required to restore normal alignment. This is particularly true in the congenital planovalgus foot in which the talus is fixed in plantar flexion. This is a special problem which will be discussed later.

Equinus deformities due to contracture of the tendo achillis and the posterior joint capsule of the ankle joint should be corrected before operation. In our original article it was stated that the equinus could be corrected after the fusion was obtained. This is true for only mild degrees of equinus. When there is equinus of more than 15 degrees, the os calcis cannot be brought forward far enough beneath the talus to allow correction of the eversion and abduction. Reduction of the valgus deformity may be very difficult to achieve in the presence of severe equinus, and even more difficult to maintain because the os calcis keeps slipping backward as a result of the pull on the tight Achilles tendon. If the equinus cannot be corrected with wedging casts before operation the heel cord should be lengthened. This, of course, can be done at the time of subtalar fusion. This is particularly applicable to the equinovalgus deformity occurring in spastic paralysis. Another cause of failure is related to the fact that there is deformity distal to the talonavicular and calcaneocuboid joints. There may be hypermobility of the distal joints so that there is depression of the longitudinal arch distal to the talonavicular joint and abduction of the forefoot through the cuneiform metatarsal area.

When the deformity has been present for four or five years, fixed deformities may appear in the fore part of the foot. It is well to realize that, if the heel is everted and the metatarsal heads are flat on the supporting surface, the front part of the foot actually is in relative varus in respect to the talocalcaneal bone mass. If the eversion of the heel is corrected and held with a subtalar fusion, the metatarsals will be in varus and the first metatarsal will not touch the floor. In the young child the metatarsals and cuneiforms can be molded down into correct alignment and the correction will be maintained by subsequent adaptation through growth. In the older patient the varus persists in the metatarsal region and may in fact get worse. If this is combined with a little equinus, an unfortunate situation develops,

since the patient will bear weight on only the fifth metatarsal head and thus becomes quite painful. When there is significant deformity in the distal portion of the foot the procedure of choice for the older patients is a triple arthrodesis, which remains an excellent operation for correction of foot deformities. Occasionally however the deformity is primarily in the metatarsal region. In such cases the subtalar fusion may be performed first, and subsequently a capsulotomy of the cuneiform metatarsal joints (as described by Heyman) or an osteotomy of the metatarsals will correct the adduction and varus deformity

AGE

The question is frequently raised as to the youngest age, the ideal age or the oldest age at which this procedure can be used. It can be used at any age The question is not how old the patient is but how long the deformity has been present. The patients who seem to be best suited for the procedure are those between 4 and 12 years of age. Below the age of 4 years, it is rarely indicated. Few deformities are severe enough to warrant surgery before 3 years of age. There is much more cartilage present in the bones of young children, and it is much more difficult to get good solid, osseous fixation. The one deformity that might be considered for early surgery is a congenital planovalgus foot with a plantar flexed talus. There is no upper limit on the age of the patient. The important factor is the duration of the deformity The oldest patient in our experience was 42 years old but the deformity had been present for only two years. A 6-year-old child might be too old, if the deformity had been present since his first year and had become fixed.

TENDON TRANSPLANTATION

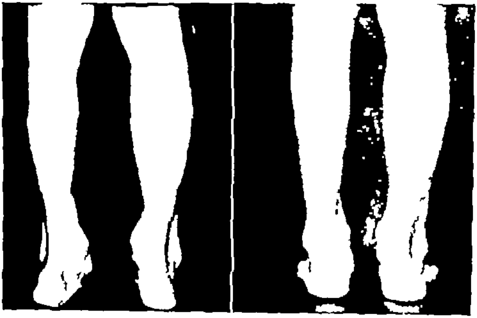
One important cause of poor results, other than the previously mentioned technical errors, would be recurrence of the deformity or overcorrection of the deformity due to inadequate correction of the muscle imbalance. In all cases where muscle imbalance exists, an effort should be made to equalize muscle strength by tendon transplantation. In the original group of fifty two patients, there were forty four who had tendon transplants. Of the eight who did not, there were six for whom there was nothing available to transplant. The transplantation may be done before the subtalar fusion in the very young child as a temporizing procedure, may be combined with the fusion or may be deferred until after fusion in order to reassess the muscle imbalance after the effect of the fusion has been observed

The type of transplant has varied considerably depending upon the age of the patient the severity of the muscle imbalance the total problem of the foot in regard to plantar flexion and dorsiflexion strength, and the muscles available for muscle transplantation. In the patient under 3 years of age with strong extensor digitorum communis, normal peroneals, and normal plantar flexion strength, a reconstruction of the posterior tibial and the spring ligament (calcaneotalonavicular) has been performed, usually as a temporizing procedure. The flexor hallucis longus and the flexor digitorum longus have been used most frequently The proximal portion of the flexor hallucis longus tendon is woven through the posterior tibial tendon and fixed to the navicular The distal portion of the severed flexor hallucis longus tendon is sutured into the side of the tendon of the flexor digitorum longus. If the flexor digitorum longus is stronger it is used in a similar manner and the distal end is sutured into the side of the flexor hallucis longus If these muscles are not available for transfer the peroneus brevis can be brought posteriorly along the flexor hallucis longus tendon sheath and fixed to the navicular If there is loss of plantar flexion strength and a developing calcaneovalgus deformity the peronei can be transferred to the apophysis of the os calcis. When there is need to reinforce the dorsiflexion power the peroneus longus may be transplanted forward to the base of the second metatarsal If there is severe deformity the peroneus brevis or the longus may be transplanted anteriorly beneath the spring ligament (plantar calcaneonavicular ligament) into the navicular This procedure should be used only in severe deformities, because a recent follow-up study has shown that some of the feet with this type of transplant have developed late varus complications.

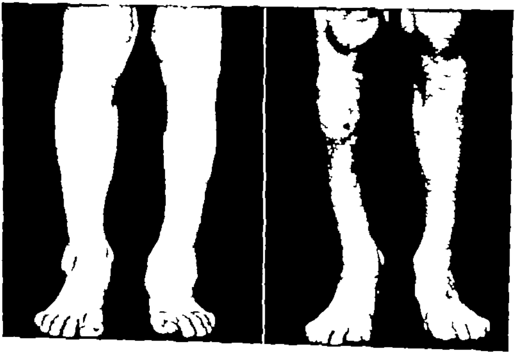
RESULTS AND LATE COMPLICATIONS

Although the extra articular fusion of the subtalar joint was recommended for correction of the valgus foot in the young child it has been used in a wide variety of valgus deformities of the foot. Originally the use of the procedure seemed justified because it appeared that, even if it were only a temporizing procedure, it did not prevent subsequent correction of the foot by triple arthrodesis. Moreover there appeared to be a good likelihood that it might be a definitive procedure in most instances. Subsequent experience has justified this initial impression. (Fig

101 *A* to *D*.) All the operations have not been perfect, and some have required triple arthrodesis to correct recurrent valgus or overcorrection with varus. The longest follow up in the series (at present, thirteen years) is that of the first patient (Fig 102 *A*). The importance of long term follow-up is well demonstrated by this patient. In 1951 he was classified as showing an excellent end result. At that time, six years after his operation he was 11 years old. Photographs and roentgenograms of his feet demonstrated excellent clinical appearance, alignment of the bones and an excellent functional result



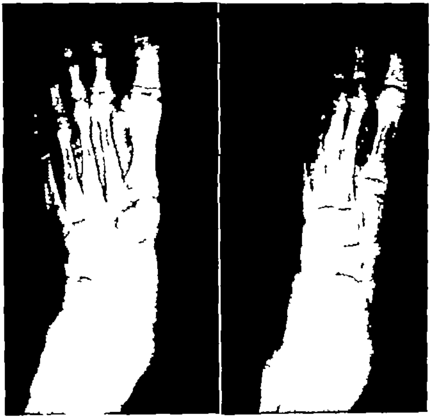
A.



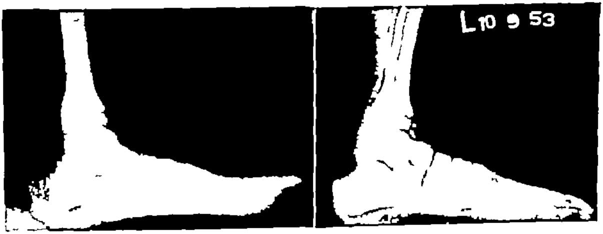
B.

Fig 101 A-D A, Moderate valgus deformity in an 8-year-old boy three years post poliomyelitis. Preoperative and postoperative photographs, back view B, Preoperative and postoperative photographs, front view

(Fig 102, *B* and *C*) There was, however a little varus deformity present. The patient was lost to follow-up in spite of many attempts to get his family to bring him back. They insisted that he was doing fine and needed no care In January 1958 when the patient was 18 years old, he was finally brought back to the clinic. He had developed a marked equinovarus deformity of the foot which had been operated upon (Fig 102 *D*) The exact relationship to the subtalar fusion is clouded a bit by the fact that he developed a similar though less severe deformity in the other foot. Nonetheless, it should be listed as a failure due to overcorrection. He has since had a triple arthrodesis performed on his left foot with a good functional result and a good cosmetic appearance (Fig 102, *E* and *F*) This repre

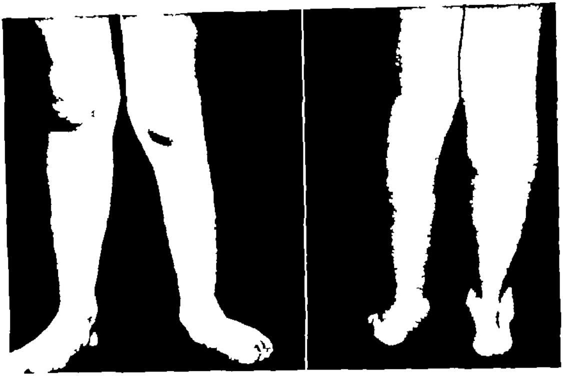


C

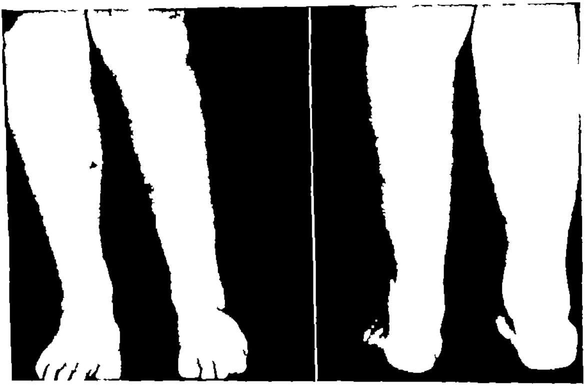


D

Fig. 101 (cont'd) C, Preoperative and postoperative roentgenograms, anteroposterior view D Preoperative and postoperative roentgenograms, lateral view



A.

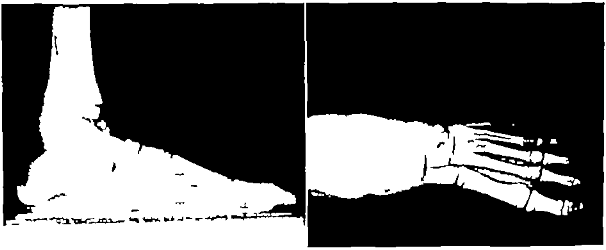


B.

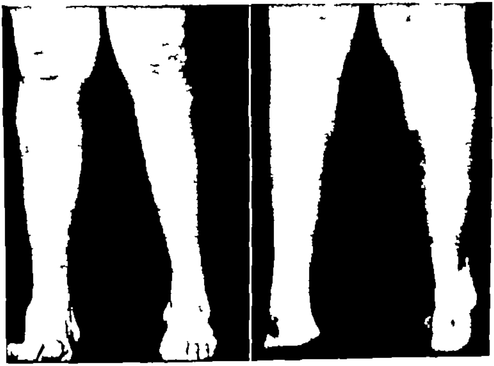
Fig. 102, A F A, Severe valgus deformity in child 5 years old in 1945 four years post poliomyelitis Preoperative photographs. B, Postoperative photographs 1951 patient 11 years old (A, From Grice D S. J Bone & Joint Surg 34 A: 927 1952.)

sents one of the six patients who have had a triple arthrodesis performed

All of the fifty-two patients whose cases were reported in 1955 have been examined within the past year and have had at least a five year follow-up with the exception of one patient who has had only a two-year follow up because a triple arthrodesis was then performed in order to correct a varus deformity In thirty-eight of the patients, growth of the foot has been completed so that there will be little tendency for the alignment of the foot to change significantly The other fourteen patients are over 11 years of age but still must be observed before they can be finally evaluated. The need for this is well demonstrated by the example of the first case presented above There are forty four patients who obtained a satisfactory result from this operation of these, seventeen were classified as ex



C



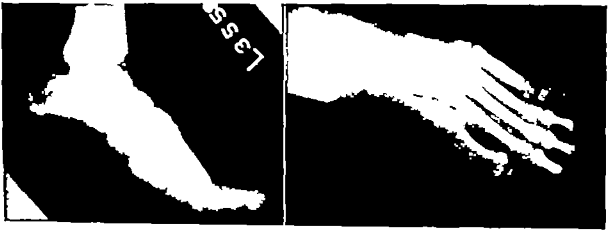
D

Fig 102 (cont d) C, Postoperative roentgenograms, anteroposterior and lateral, 1951 D, Postoperative photographs, 1958 patient 18 years old.

cellent and twenty-seven as good. In the unsatisfactory group there were eight patients, a group in which three had fair results and five had poor results. In the unsatisfactory group six patients had a secondary triple arthrodesis in order to obtain either a good functional result or a better cosmetic appearance. Three of these were done because of inadequate correction and three were performed because of overcorrection which resulted in a varus deformity. Needless to say, it is better to err in the direction of leaving the foot in a little valgus than it is to overcorrect the foot and place it in varus. The foot has a better appearance initially if it is in a little varus, but the function is better if there is a little valgus. The foot is more stable in valgus. Furthermore, there appears to be a tendency for the foot to swing into a little varus with growth. This is particularly true for those patients early in the series in whom tendon transplantation in the talonavicular region was performed when the deformity was only moderate. This transplantation should be reserved for only the more severe deformities. Although a little valgus is desirable, it does not follow that more valgus is even better! If the subtalar joint is fused with the foot in moderate valgus, a deformity is produced similar to that found in congenital talocalcaneal coalition. Peroneal spasm has developed in surgically treated feet similar to that observed in talocalcaneal coalition, if the foot has been left in valgus. Correction of the valgus position has relieved the peroneal spasm.

LATE CHANGES IN ADJACENT ARTICULATIONS

There has been some concern expressed that fusion of the subtalar joint in the young child may



E

F

Fig. 102 (cont'd) E, Postoperative roentgenograms made March 5, 1958. Anteroposterior and lateral views, showing inversion and adduction fatigue fracture of fifth metatarsal. F, Postoperative triple arthrodesis July 15, 1958, for correction of varus. Mild adduction of metatarsals still present.

in effect, produce a situation similar to that found in congenital talocalcaneal coalition. This condition has been carefully studied and reported by Dr R. I Harris of Toronto The association of peroneal spasm and secondary changes in the adjacent tarsal joints with talocalcaneal coalition has been well documented. The changes in the talonavicular region are quite characteristic and consist of lipping of the superior border of the talonavicular joint and a scalloped defect in the superior and lateral border in the head of the talus. It is our opinion that this change is related to the valgus position of the foot rather than the loss of motion in the subtalar joint. The reason for this concept is the fact that similar changes have been observed in severe paralytic valgus deformities occurring in flexible feet. On the other hand, these changes have not been found in feet with varus deformities, whether the subtalar joint has been fused or has not.

Roentgenograms of the feet in this series have been reviewed during the past year in order to determine what changes have appeared in the ankle joint and the mid-tarsal joints. Two patients had minimal changes in the talonavicular joint, consisting of decreased width of the joint and slight hypertrophic lipping at the superior aspect, similar to that observed in some patients with talocalcaneal coalition. Eight patients exhibited changes in the cuneonavicular joint which have not been observed in flexible valgus feet (Fig 103) The change consists

A.

B

C.

Fig 103. A, Patient 5 years old showing severe valgus deformity February 1951 two years postpoliomyelitis B, In October 1953 two years after fusion and a transplantation of the peroneus brevis to the base of the navicular See notched defect in superior aspect of the navicular adjacent to the cuneiform. C, Seven years after fusion the navicula now (July 1958) appears normal density and contour

of an apparent notching of the superior distal aspect of the navicular. The defects suggest the appearance of a localized aseptic necrosis similar to that seen in Köhler's disease. The initial change may be an increased density; then there is absorption and, finally, replacement. In some patients, the defects have persisted and in others they have disappeared. It is conceivable that these changes are caused by the greater impact thrust upon the cuneonavicular joint because of the absence of motion in the subtalar region. A few patients have shown minimal reaction in the tibiotalar joint, similar to that observed in patients who have had triple arthrodesis. This is first manifested by the appearance of irregular calcification on the anterior aspect of the tibia and the superior aspect of the talus at the site of attachment of the joint capsule. These changes, though mild, are analogous to those reported by O'Donoghue in athletes. It may be that this represents increased strain on the ankle joint because of the loss of motion in the subtalar joint. Whether this will be more pronounced in young children who have had subtalar fusions than it will be in older patients who have had triple arthrodesis cannot be determined at this time. There is nothing thus far to suggest that it will be greater or more frequent. Certainly it has not been shown that any significant changes will occur early. In fact, the converse has been true. Inasmuch as more normal alignment is obtained by this procedure, there appears to be less change in the talonavicular joint than was previously observed in untreated, flexible valgus deformities.

CONGENITAL CONVEX PES VALGUS—PLANTAR FLEXED TALUS

The question has been raised repeatedly as to the application of subtalar fusion in the treatment of congenital convex pes valgus, or rocker foot. This is a severe deformity of the foot in which the talus is in fixed plantar flexion and the foot is displaced laterally into valgus in respect to the talus. It is a congenital anomaly representing a failure of the talus to be displaced out of equinus and assume its normal horizontal position. The x-ray appearance of such a foot is very similar to that of a severe valgus deformity associated with paralysis of the anterior and posterior tibial muscles. There are significant and essential structural differences, however. The paralytic valgus foot in the young child is a flexible foot, and the normal alignment of the bones can be obtained by properly positioning the foot. Subtalar fusion, with the insertion of bone grafts, is used in such a foot merely to maintain the position that has been obtained. In the congenital rocker foot with plantar flexed talus the deformity is fixed and is associated with multiple anomalous structures. The primary problem is one of restoring normal alignment, rather than of maintaining it with the subtalar fusion. However, once the proper alignment has been restored, subtalar fusion may prove to be a valuable adjunct in treatment.

The treatment of congenital rocker foot should begin at birth, when the ligamentous and capsular structures are pliable enough to allow at least partial restoration of alignment through plaster fixation. The older the patient is at the time treatment is initiated the more fixed the deformity and the more difficult the treatment will be. At birth the foot may have a grotesque appearance in which the fundamental attitude seems to be a severe calcaneovalgus (Fig. 104, *A*).

It would be well to point out that the congenital rocker foot should not be confused with the normal foot which assumes a positional attitude of calcaneovalgus. The foot contour in this latter type of deformity is normal, and the foot is merely displaced in extreme dorsiflexion at the ankle joint. This common type of calcaneovalgus deformity is a positional attitude which is rapidly and completely corrected by means of passive exercises and supportive apparatus.

The congenital convex pes valgus, in addition to being maintained in severe calcaneovalgus, also has a rocker contour to the sole of the foot, and the foot is markedly restricted in plantar flexion. Roentgenograms of the feet reveal that the talus is in marked plantar flexion, the os calcis is everted and displaced laterally and posteriorly in respect to the talus, and the foot is angulated dorsally through the talonavicular joint. The anomalous relations of the talonavicular region are not apparent from roentgenograms taken at birth because there is no ossification center for the navicular (Fig. 104, *B*). At later operation and by dissection of specimens, it has been demonstrated that the navicular is displaced upward and proximally so that it lies on top of the neck of the talus. The initial treatment with manipulation and the application of plaster casts is directed toward bringing the foot down into equinus and then into adduction and varus, so that the os calcis is placed beneath the talus. Although this is the primary objective, efforts also are made to correct the convex contour of the sole and establish a longitudinal arch by molding the forefoot into equinus in an effort to

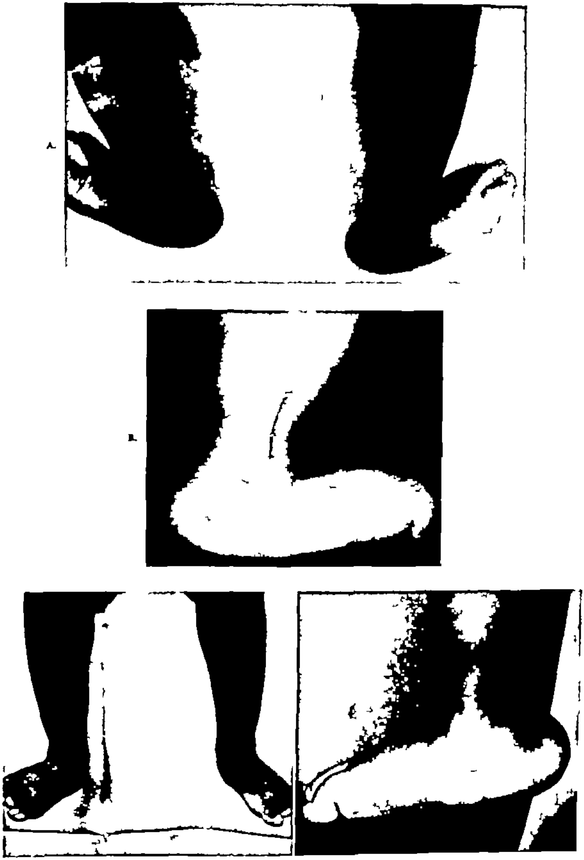


Fig. 104 A E. For legend see opposite page.

D.

E.

Fig. 104 A-E. A, Congenital convex pes planus in an infant, bilateral rocker deformities. B, Roentgenogram of right foot shows 90 degree plantar flexion of talus. C, Patient 14 months old, after treatment with casts. Front view shows fixed eversion of right foot. Medial view shows persistent rocker contour. D, Roentgenogram at 14 months showing right foot in maximum dorsiflexion, with the talus in equinus and break in contour at the talonavicular and calcaneocuboid joints. E, Postoperative view at 15 months shows improved alignment, no ossification center for navicular. Horizontal wire fixes talonavicular joint. Vertical wire fixes talocalcaneal joint.

bring the navicular forward to articulate with the head of the talus. After it has been demonstrated by x ray examination that the os calcis is in proper relationship to the talus, the foot is allowed to remain in this position for several weeks so that the ligaments can adapt to the change. Efforts are then made to hold the foot in adduction and varus to keep the os calcis beneath the talus, and the foot is brought into dorsiflexion. This can best be done by applying the cast with the foot in equinovarus and then wedging the foot up into dorsiflexion. In the mild forms of this deformity these efforts are usually successful in restoring satisfactory alignment and a desirable appearance of the foot.

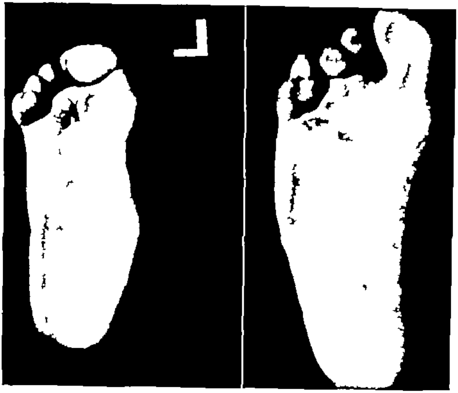
When there is more severe deformity it is usually not possible to bring the talus out of equinus, and the navicular remains on the dorsum of the neck of the talus. As soon as the casts are removed the deformity recurs, although it is not so severe as it was at first. When this situation presents, it is advisable to operate and release the soft tissue contractures. (Fig 104 *C*) In recent years, this operative correction has been performed in younger children from 12 to 18 months old, and the ease with which correction of severe deformities has been obtained has been very gratifying. The operative technique is very similar to that described by Hark in 1950 but with some modifications. In the young child we have thought it advisable to correct the deformity of the foot first before correcting the equinus of the talus. Hark in 1950 recommended that this procedure be deferred for use with an older age group but our initial experience as well as that of other surgeons would indicate that surgery in the younger child would result in better correction. Osmond-Clarke in 1956 reported his experiences with two children with bilateral deformities which had been successfully treated by open operation. He used both medial and lateral incisions but most of the dissection was performed through the lateral incision. The subluxation of the talonavicular and subtalar joints was reduced after freeing of the talus and navicular by soft tissue dissection. The tendon of the peroneus brevis was transplanted through the neck of the talus to hold it in position. The author stated " ... in each case the immediate correction has been gratifying, though it has not been possible always to maintain the talus in its normal horizontal position." No heel cord lengthening or posterior capsulotomies were performed. It would seem likely that unless the equinus of the talus is corrected the deformity would recur. This has been our experience to date with this procedure. We have used transplantation of the peroneus brevis to the neck of the talus but have more frequently used the anterior tibial tendon to restore support to the head of the talus. Our experiences, like those of Osmond-Clarke, are of too recent origin to indicate end results. However, we are reporting them along with the work of Hark and Osmond-Clarke, in order to contribute to the knowledge available in this field.

Operative Procedure. A tourniquet is applied to the mid thigh to permit an anatomical dissection. The medial aspect of the ankle joint in the mid tarsal region is exposed through an S-shaped incision, beginning with the vertical end just anterior to the medial malleolus and following a horizontal sweep forward along the dorsal aspect of the foot to the metatarsal cuneiform joint, where it turns downward. This affords adequate exposure from the anterior aspect of the ankle joint to the insertion of the anterior tibial tendon. The dissection is carried down through the subcutaneous fat to the ligamentous structures, and the subcutaneous fat is reflected as a layer off the deep capsular structures. The navicular is found lying on top of the neck of the talus and it articulates with the tibia. There is no tibiotalar joint capsule but, rather a tibionavicular joint capsule. This joint capsule is divided transversely close to the tibia so that there will be a cuff of capsule attached to the navicular for closure at the end of the operation. The capsule is then divided medially freeing the navicular from the tibia and the superior aspect of the talus. The anterior tibial is detached from its insertion, and the navicular can then usually be brought down into a normal relation to the head of the talus. (It is readily understood after observing these anomalous relationships why the deformity is so resistant to correction with plaster.) A lateral incision is made over the tarsal sinus similar to that used for subtalar fusion. The transverse tarsal ligament is incised and the ligamentous structures and the tarsal sinus are divided to allow the sinus tarsi to be opened up. The capsule between the calcaneus and the talus is divided and the normal alignment of the foot restored by displacing the foot into plantar flexion, inversion, and adduction. The navicular is maintained in correct relationship to the talus by transfixing both bones with a size 0.062 Kirschner wire. The relation of the os calcis to the talus is maintained by passing another wire from the sole of the foot upward through the calcaneus into the talus. (Fig 104 *D* and *E*) Excellent alignment is

A.

B.

Fig. 105, A-D. A, Congenital convex pes planus in a patient 6 years old. Photographs are preoperative and postoperative medial views. B, Roentgenograms, preoperative and postoperative. Note that the navicular was on the dorsum of the talus before operation. At operation the navicular was placed in normal relation to the talus but was not maintained. For this reason, transfixion wires were subsequently used.

C


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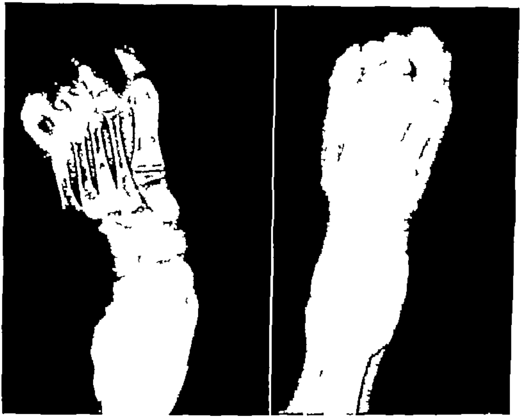


Fig 105 (cont d) C, Photographs showing preoperative and postoperative plantar views. D Preoperativ and postoperativ anteroposterior roentgenograms. Note relative metatarsal adduction i preoperativ ew—more pparent in postoperativ view

usually obtained by this dissection and the foot is quite stable with the wire transfixion. The anterior tibial is then redirected proximally and medially so that it passes along the medial aspect of the neck of the talus through the inferior joint capsule beneath the head of the talus, along the spring ligament, and is fixed to the exposed surface of the inferior aspect of the navicular with No. 2-0 silk sutures. Inasmuch as the foot is quite stable after the insertion of the Kirschner wires, the foot should be placed in the maximum amount of dorsiflexion possible without placing too much stress upon the wires. The wound is then closed with interrupted sutures of No. 4-0 silk and No 5-0 silk to the skin and a long leg cast is applied.

After ten to fourteen days the cast is changed and the sutures removed. It is usually possible to correct the equinus deformity somewhat more at this time. If residual equinus persists, the cast is applied so the foot can be wedged up into dorsiflexion six to eight weeks after operation. The position of the foot should be checked by x-ray examination to be sure the foot is not becoming displaced in respect to the talus as it is brought up into dorsiflexion. It is quite important to see that the talus is brought up out of equinus with the rest of the foot. The Kirschner wires are removed about twelve weeks after operation, and active exercises are started. If the equinus deformity cannot be corrected with manipulations, wedgings, and cast changes, it will be necessary to lengthen the heel cord and do a posterior capsulotomy of the tibiotalar joint.

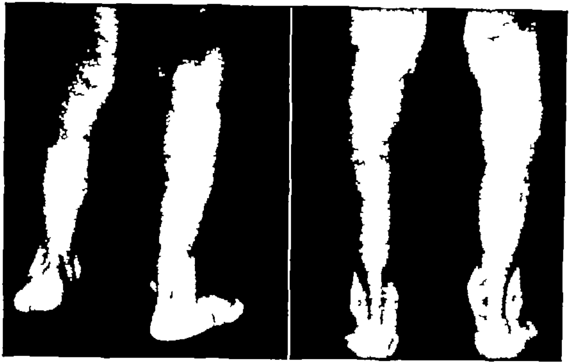
Fusion of the subtalar joint has not been used in the very young age group because it is hoped that a satisfactory result may be obtained without fusion. If there is evident recurrence of the deformity following the soft tissue reconstruction, stabilization of the subtalar joint will be indicated to maintain the correction. It should always be remembered that subtalar fusion should not be performed until all elements of the deformity have been corrected either before or in conjunction with the subtalar fusion. When correction of congenital convex pes planus is attempted in the older child, similar soft tissue release and reconstruction is performed. The deformity however is much more difficult to correct in older children and probably impossible in severe cases for patients over 8 years of age (Fig 105.) Beyond this age the deformity should be corrected by triple arthrodesis when growth is completed. In older children it is usually necessary to lengthen the heel cord and divide the posterior ankle joint capsule in order to correct the deformity. Stabilization of the subtalar joint to maintain the correction is also usually required in the older children.

CEREBRAL PALSY—VALGUS DEFORMITIES

The subtalar fusion with bone grafts has been a valuable aid in the treatment of valgus deformities occurring in cerebral palsy patients with spasticity of the lower extremities. The indications for operation are the same as in other children, but as Baker and Dodelin have pointed out, "The deformity is the result of a spastic or tension paralysis of the peroneal and triceps surae muscles," rather than a paralysis of the anterior and posterior tibial muscles. When there is a spastic equinovalgus deformity present, the equinus element should be corrected before or at the time of subtalar fusion. Correction of the equinus deformity and stabilization of the subtalar joint may restore balance to the foot, since the overactivity of the peroneal muscles may be diminished as well as that of the triceps surae. The need for tendon transplantation should be evaluated after the original procedure and will infrequently be needed. In the series reported by Baker and Dodelin in which subtalar fusion was performed in twenty nine feet, lengthening of the gastrocnemius aponeurosis was performed twenty-five times and recession of the head of the gastrocnemius four times. There were only two peroneal tendon transplantations done in the whole series, indicating the need for careful assessment. In five cases, overcorrection followed the procedure due to the development of overactivity of the posterior tibial muscles, and in two cases tenotomy of the posterior tibial tendon was performed to correct the varus deformity. Excellent results may be obtained by stabilization of the subtalar joint in cerebral palsy patients with valgus deformities, but it is necessary to correct existing equinus deformities in order to obtain satisfactory correction of the alignment of the foot. Tendon transplantation should be deferred until after stabilization has been performed. Care should be taken not to produce an overcorrected foot. (Fig 106.)

TALOCALCANEAL COALITION

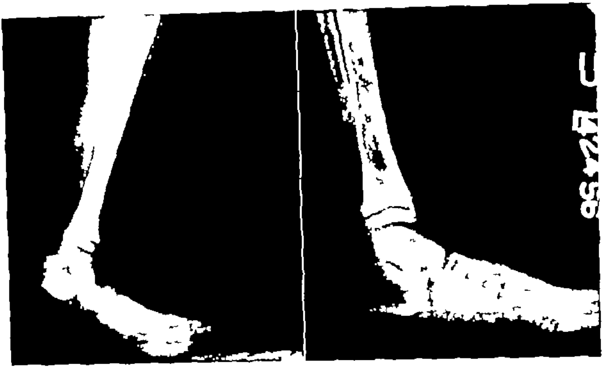
The diagnosis of a congenital talocalcaneal coalition in the young child is difficult because the area of synostosis is usually cartilaginous and cannot be demonstrated by x ray with the special views described by Harris. For this reason, experience with subtalar fusion for correction of the deformity in



A.

B.

Fig. 106, A-D A, Equinovalgus spastic hemiplegia. Patient 5 years old. Preoperative and postoperative photographs, back view. B, *Preoperative and postoperative photographs, front view.*



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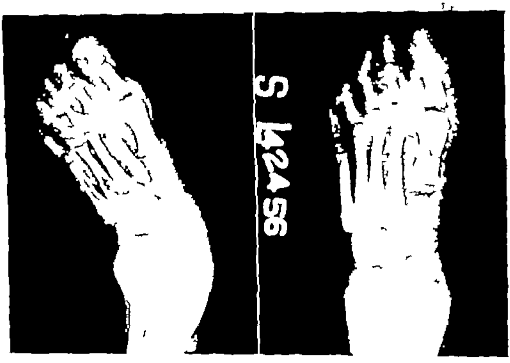


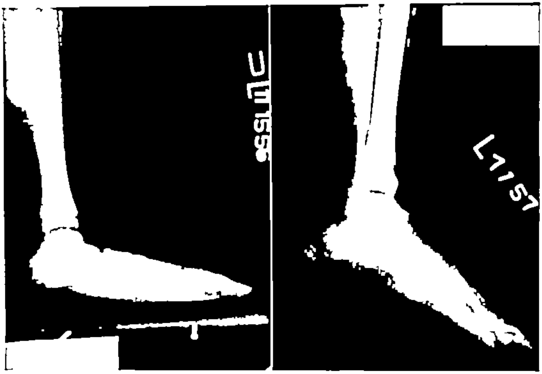
D

Fig. 106 (cont'd) C, Preoperative and postoperative lateral roentgenograms. Heel cord lengthening and posterior capsulotomy performed at time of fusion. No transplants. D, Preoperative and postoperative anteroposterior views.

A

B

Fig. 107 A-D Congenital talocalcaneal coalition with peroneal spasm A, Preoperative photographs B, Postoperative photographs



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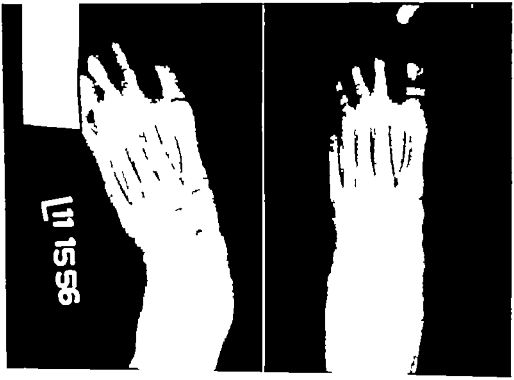

D

Fig 107 (cont'd) C, Preoperative and postoperative lateral roentgenograms. D Preoperative and postoperative anteroposterior roentgenograms.

young children under the age of 8 years may be limited If the condition is not recognized until the age of 10 or 12 years, there is usually so much deformity in the other mid tarsal joints that triple arthrodesis is the procedure of choice. It would be well to point out that the majority of children with rigid valgus feet and associated peroneal muscle spasm can usually be relieved of their symptoms with adequate arch supports and do not require surgical intervention until they get older Occasionally the diagnosis of talocalcaneal coalition will be made in a child who has not been relieved with non surgical measures. In one such case the area of coalition in the region of the sustentaculum tali was excised, the alignment of the foot corrected, and a subtalar fusion performed. An excellent cosmetic result was obtained and the peroneal spasm relieved. (Fig 107 *A* to *D*)

SUMMARY

Fusion of the subtalar joint with bone grafts is a simple procedure which is useful in a variety of foot deformities. The precise indications and the limitations of the procedure are still being defined. It is a means of obtaining stability of the subtalar joint in the young child without interfering with the subsequent growth of the foot. It is particularly well adapted to stabilization of the flail foot and correction of the valgus foot It would seem to have little application in the varus deformity Correction of the varus deformity in the young child may be accomplished by a release of the contracted structures of the medial and plantar aspects of the foot and correction of the muscle imbalance by tendon transplantation.

In properly selected patients when the operation has been well performed, there are strong indications that it will be a definitive procedure The later changes in the adjacent articular structures have been minimal and would appear to be no more marked than those seen in relationship to triple arthrodesis. If further treatment should be necessary after subtalar fusion, it is relatively easy to resect the arthrodesed subtalar joint and proceed with a triple arthrodesis The height of the foot will have been maintained during the growing period, and a better result will be obtained with triple arthrodesis than would have been possible if the subtalar fusion had not been performed.

The author would like to express his appreciation to William T Green, M.D and to the Children s Medical Center Boston, for granting permission to publish this work which was in large part performed t the Children s Medical Center

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PART FOUR

THE KNEE

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Concourse New York

INJURIES AND AFFLICTIONS OF THE MENISCI OF THE KNEE

The function of the menisci of the knee has been investigated by anatomists and clinicians (Fick, Voshell, Brantigan, and others) The structure of the normal and of the abnormal menisci is also well known. Dissections of the human knee joint revealed the character of the menisci and their relationship to the surrounding structures: ligaments, tendons, muscles, and neurovascular supply Additional information of value was obtained from studies in embryology and comparative anatomy

COMPARATIVE ANATOMY

My own investigations of the embryology of the menisci showed that the semilunar form of each meniscus appears at a very early age in the fetal development. In embryos between 11 and 20 mm. in length, which corresponds approximately to 42 to 50 days of pregnancy the femur and tibia gradually assume their form as chondrified units in blastemal tissue. The blastemal matrix connects the tibia and femur without interruption and is called by the majority of investigators "intermediate zone of the blastema." Some others call it "blastemal disc." This probably induced some people to believe that the zone actually represents a disc (Fig 108) Actually the menisci become visible as separate structures after the eighth week of fetal development (about 60 mm. in size) and are well defined after nine weeks, when the fetus is about 70 mm. in size (Gray and Gardner)

Observations made by other investigators show that the menisci assume the normal adult form at a very early stage (McDermott, Bardeen, Grynfeltt, and Nicolas) Apparently the menisci and all the intra-articular ligaments develop in the blastema of the knee. In my investigation, on embryos of 14 21.5 30 50, 60 80 and 120 mm. in size, which correspond to 40-45 50-52, 56-58 68-70 70-72 78-80 and 108-110 days of development, approximately it was found that the menisci as separate structures appear very early In a section of a 30 mm. embryo, the lateral and medial menisci can be distinguished as two triangular masses connected with the capsule of the knee (Fig 109) A greater magnification of this area (Figs. 110 and 111) shows a very well defined meniscus with a sharp internal edge at both the lateral and the medial side of the joint. In an embryo of about 70 to 72 days of pregnancy the medial and lateral menisci are well defined and present their typical semilunar form (Fig. 112)

Many dissections of the knee joint were performed on stillborn babies ranging between 26 and 38 weeks. These dissections revealed that the knee of newborn babies exhibits the adult configuration of the medial and lateral menisci.

Additional comparative anatomical studies were made on different species of mammals, reptiles, and amphibians. These dissections showed that most of the mammals had a typical semilunar or circular form of menisci similar to the configuration of the human menisci. In the reptiles and amphibians, the configuration of the meniscus is somewhat different. In the amphibian, represented by the frog the configuration of the meniscus is similar to that in the

Fig. 108. Left knee of n embryo 21.5 mm. (approximately 6 weeks) (×30)

Fig. 109. Knee of embryo 30 mm. (approximately 60 to 65 days) (×30.)

Fig 110. Same as Fig 109 showing lateral meniscus (×200.)

Fig. 111 Same as Fig. 109 showing medial meniscus. (×200)

Fig. 112. Sagittal section through lateral femoral condyle of right knee of embryo 50 mm. (70 to 72 days) (×30.)

human being only it is modified by the presence of a femorofibular joint. In the reptilians represented by the lizard, the form of the menisci is quite different. The special function of the reptilian knee shows that the medial meniscus is semilunar and that the lateral meniscus is irregularly shaped, modified by the special function of the femorofibular joint which plays an important role in the activity of the reptilian knee.

The most interesting difference between the menisci of the human knee and the knees of other mammals is related to the connection of the anterior and posterior horns of the lateral meniscus to the tibial plateau.

As is well known, the medial and lateral menisci are both attached in the human knee to the tibia. The anterior horns of the medial and lateral menisci are attached to the tibia. The posterior horn of each meniscus is also firmly attached to the tibia. In the knee of the mammals, the anterior attachment of the lateral and medial menisci is similar to the attachment in the human knee But posteriorly the attachment of the lateral meniscus to the tibia is absent in all mammals, and it is actually free over the tibia. The posterior horn of the lateral meniscus is, however attached by two ligaments to the lateral surface of the medial condyle of the femur One ligament is anterior to the posterior cruciate ligament and the other is posterior to it. In motion of the knee joint, the lateral meniscus moves more freely than the medial meniscus.

In the human knee joint, the function of the menisci is well established The human knee has three types of motion. It is not a purely hinge type joint with extension and flexion only for it also has a gliding and a rotatory component. The gliding of the menisci is anterior in extension and posterior in flexion. The rotation occurs around a longitudinal axis located nearer the center of the medial meniscus permitting the lateral meniscus to move within a greater range.

The medial meniscus is attached to the anterior

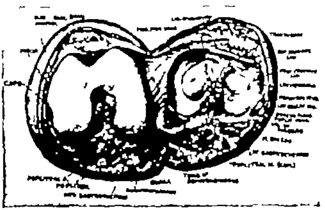

Fig 113. Transverse section of the right knee joint, opening the joint (From Kaplan, E. B. Surg. Gynec. & Obst. 104: 346, 1957 by permission of Surgery Gynecology & Obstetrics.)

Fig 114. Dissection of lateral aspect of the left knee joint. (From Kaplan, E. B: Surg. Gynec. & Obst. 104: 346 1957 by permission of Surgery Gynecology & Obstetrics.)

increase of the intra articular fluid or with a healed tear of the medial collateral ligament.

On the lateral side, the diagnosis of an injury to the lateral meniscus might be somewhat more difficult, although it presents, to a certain extent, signs identical with injuries of the medial meniscus. Occasionally although rarely the lateral meniscus may present small ossicles in its peripheral parts, either anteriorly or posteriorly. Also, a sesamoid bone might be found in the thickness of the popliteus tendon and the injury might occur in this area. Roentgenograms of ossicles of the lateral meniscus or in the popliteus tendon may lead to an erroneous diagnosis of osteochondral bodies, which may not be found if the knee joint is opened for the purpose of removing such bodies.

Increase in the instability of the knee joint whether lateral anterior or posterior might be due to more factors than actually suspected. Tears of one of the cruciate ligaments alone might not produce sufficient instability to require repair. If however a tear of one of the cruciate ligaments is associated with injuries to one of the collateral ligaments or the popliteus tendon or the iliotibial band the disability may be sufficiently serious to require repair but, in the analysis of the injured structures, these additional injuries must be taken into consideration and dealt with accordingly.

SURGICAL APPROACHES

Many adequate incisions are known for treatment of the menisci, but occasionally the incision must be extended for dealing with situations not suspected previous to the operation.

In my experience, an oblique incision over the lateral aspect of the knee joint, beginning approximately slightly distal to the upper pole of the patella, from the lateral border of the patella and running obliquely across the knee joint to a point about 2 cm. proximal to the tip of the fibular head, permits a satisfactory exposure of the knee. It also permits the surgeon to avoid dividing such important structures as the iliotibial band, the collateral ligament, or the biceps insertion (Fig 116). After exposure of the deeper structures, an oblique incision somewhat parallel to the skin incision can be made between the patella and the iliotibial band. Another incision can be made posterior to the iliotibial band,

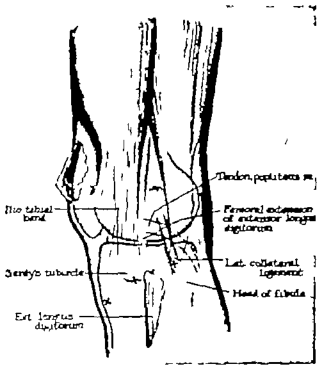

Fig. 116. Lateral aspect of the left knee joint. (From Kaplan, E. B. Surg Gynec & Obst 104 346 1957 by permission of Surgery Gynecology & Obstetrics.)

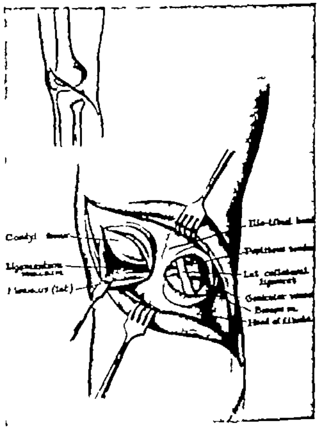

Fig. 117 Incision and anatomy of lateral approach to the knee joint. (From Kaplan, E. B. Surg Gynec. & Obst. 104: 346 1957 by permission of Surgery Gynecology & Obstetrics.)

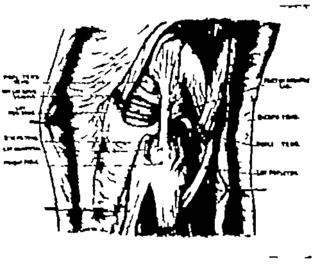

Fig. 118. Details of anatomy of lateral aspect of the knee joint. (From Kaplan, E. B., Surg. Gynec. & Obst. 104: 346, 1957 by permission of Surgery Gynecology & Obstetrics.)

running between the band and the biceps muscle (Fig 117) If necessary through the same skin incision extended somewhat more posteriorly an additional approach can be made between the biceps tendon and the lateral gastrocnemius (Fig 118) Of course the posterior incision will be made only in special cases where the posterior aspect of the knee joint from the lateral side must be exposed.

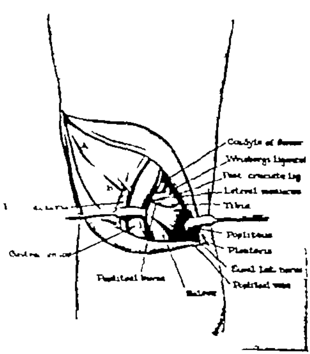

Fig. 119 Posterior extension of the incision. (From Kaplan, E B Surg. Gynec & Obst. 104 346, 1957 by permission of Surgery Gynecology & Obstetrics.)

However this incision made with the knee slightly flexed permits a satisfactory approach to the posterior area of the joint. If required the gastrocnemius muscle can be transected and the posterior aspect widely exposed after proper retraction (Fig 119)

On the medial side a similar oblique incision can be made from a symmetrical point over the medial border of the patella and directed obliquely across the knee to a point 2 cm distal to the posteromedial angle of the tibial tuberosity Through this incision the medial aspect of the knee can be exposed satisfactorily and, if necessary extended to the popliteal space Retraction of the semitendinosus, semimembranosus, and gracilis tendons forward with the knee slightly flexed gives a very satisfactory approach between the medial gastrocnemius and these tendons, exposing the posterior aspect of the medial side of the posterior capsule. In ordinary surgery on the meniscus, the extended approach is not necessary Postoperative healing of those incisions has proved very satisfactory

SUMMARY

Embryological and comparative anatomical studies have indicated the development and configuration of the menisci. Both the lateral and the medial menisci have the same configuration from the earliest stages of embryonal development to adult life. The mammals also have the same form of menisci.

Discoid menisci are the result of loss of attachment of the posterior horn to the tibial plateau.

Injuries of the menisci must be differentiated from other injuries especially in the occasional presence of ossicles in the substance of the menisci or the popliteus tendon

Additional factors in knee stability are discussed.

Surgical approaches to the lateral and the medial aspects of the knee joint are described.

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INTERNAL DERANGEMENTS OF THE KNEE

The term "internal derangement," applied to the knee may be defined as a clinical entity which is manifested chiefly by the symptom of locking either momentary or prolonged. Omitted from this course are fractures, ligamentous injuries, and inflammatory conditions. We shall be concerned chiefly with lesions of the menisci, osteochondritis dissecans, osteochondromatosis, and the loose bodies associated with osteoarthritis or trauma. Also included because of the occasional occurrence of momentary locking is that degenerative process of the articular cartilage of patella and femur known as chondromalacia.

The knee of man is probably the most vulnerable of his joints to injury because, like the elephant he has the distinction among mammals of bearing weight upon this joint in extension. The flexed position which characterizes other species acts as a shock absorber the so-called "knee action." Also the knee is not a purely hinge type joint, because the movements of flexion and extension are accompanied by a rotation of the femur on the tibia. This complex movement requires the associated gliding of the menisci, which may be injured in the process. We shall take up the various clinical entities in turn, from the standpoint of causation, diagnosis findings at operation, microscopic studies, and principles of treatment

LESIONS OF THE MENISCI

The semilunar fibrocartilages serve to accommodate the surfaces of the femoral and tibial condyles to each other during the movements of flexion and extension combined with a slight gliding and rotation of femur on tibia while the latter is fixed during weight bearing Each meniscus slips backward on the tibia during flexion, the lateral to a greater extent. In this process, a meniscus is likely to be pinched between femur and tibia and thus torn as the knee goes from acute flexion into full extension during weight bearing The lateral meniscus is injured less frequently (in a ratio of about one to five) probably because of its greater mobility and the fact that its posterior horn is pulled out of danger by the ligament of Wrisberg and the popliteus muscle

A locking of the knee in slight to moderate flexion is the most diagnostic sign of a meniscal tear and is usually found except in lesions limited to the posterior horn, in which cases "a click" may be observed during flexion. A locking which can be reduced by manipulation suggests a longitudinal tear (the bucket handle type) or possibly a small peripheral tear An irreducible locking is likely to be due to a tear of the anterior horn. An immediate swelling of the knee may be caused by a tear of the peripheral portion of the meniscus with hemorrhage Tenderness is a useful sign in determining which cartilage is involved. Pain on adducting the extended knee suggests a tear of the medial meniscus as distinguished from a partial tear of the internal lateral ligament, with which it may be confused, and which latter lesion causes pain when the knee is abducted. Routine roentgenograms are of value only in ruling out other possible causes of locking. My own experience has not included the injection of air or other contrast media into the knee because of the slight hazards of infection or air embolism and because the clinical

Fig 120 Tear of meniscus, showing no attempt at repair

history and physical findings usually provide a clear indication for the exploration of the knee.

One is justified in attempting manipulative reduction in the first episode of locking of a knee by the maneuver of flexion, abduction, and external rotation of the knee followed by internal rotation and extension. If reduction is accomplished, it should be followed by three weeks of immobilization in a plaster cylinder A small peripheral tear may thus be permitted to heal. The initial locking of the knee may also be treated by aspiration (when necessary) followed by a few days of traction. If full extension is obtained a plaster cylinder is then applied for three weeks.

In most cases, tears of a meniscus are more extensive and occur through the nonvascular portion in which no healing may be expected (Fig 120) In the event that a manipulative reduction is impossible or in case a recurrence of the locking occurs, a prompt arthrotomy is advisable A delay of several months during which repeated episodes of locking occur has been found at operation to have resulted in degenerative changes in the articular cartilage of the femur and tibia. Every arthrotomy after diagnosis of a suspected meniscal tear should be made through an incision which is adequate to permit a visualization of the anterior cruciate ligament and the anterior third of the other meniscus, as well as to provide room for the exposure and removal of the injured meniscus The undersurface of the patella should also be seen or palpated to de

Fig 121 Use of tonsil snare to divide attachment of posterior horn of meniscus.

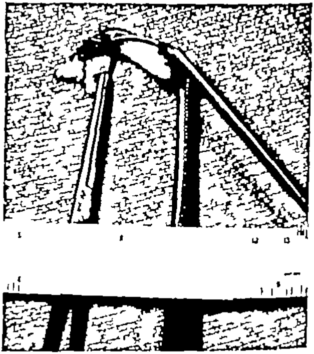

Fig 122. Tonsil snare in position used to divide attachment of meniscus which had already torn loose posteriorly and had been dissected free anteriorly

termine the degree of chondromalacia the treatment of which will be discussed later

Some difference of opinion exists as to the amount of meniscus which should be removed. It is my practice to remove only the displaced loop of carti-

Fig. 123. Types of tears of menisci.

lage in the longitudinal (bucket handle) type of tear because this can be accomplished with a minimum of trauma using a modified tonsil snare to divide its posterior end (Figs. 121 and 122) If the remaining peripheral portion of the meniscus appears to be normal it seems logical to leave it, in the hope of preventing the osteoarthritic changes which have sometimes been seen to develop five or ten years after total meniscectomy Some writers hold that any torn meniscus is pathological and should be completely excised Other types of meniscal tears are treated by the removal of as much of the cartilage as is possible without undue trauma to the articular surfaces of the knee Occasionally a tear involving the posterior third of the meniscus cannot be seen until the surgeon has separated the anterior portion from its peripheral attachment. Therefore, it is my practice to proceed with the excision of a meniscus when the clinical findings indicate a lesion of this structure If no tear is found, the meniscus is considered to have been "hypermobile Statistics indicate that the removal of apparently normal menisci has been beneficial in a satisfactory percentage of cases. However chondromalacia of the patella may produce the clinical picture associated with a meniscal tear and should be kept in mind.

Postoperative treatment involves the use of quadriceps muscle setting exercises in which the patient has been instructed prior to operation and which he performs religiously at least ten times every hour beginning on the first or second day after operation. After leaving the hospital, he carries out the progres-

Fig 124. On left: longitudinal tears of menisci. On right (from top to bottom): excised portion of meniscus with bucket handle tear discoid meniscus, cyst of meniscus.

sive quadriceps resistance exercises of De Lorme for at least one month. I usually apply a plaster cylinder in the operating room before removal of the tourniquet, split and spread this cast in the region of the knee a few hours later and remove it entirely after four days. The patient is then permitted to walk using a cane or crutch if necessary

A study of the menisci which have been excised shows a great variety of lesions (Figs. 123 and 124) with regard both to the location and extent of the tear or tears and to the degenerative changes in the untorn portion. Microscopically these lesions are characterized by the complete absence of reparative processes, presumably because of the lack of blood supply A deposit of calcium in the meniscus is a rare finding and is usually demonstrated by the roentgenogram. The discoid meniscus represents a persistence of the fetal shape of this structure. This type of meniscus usually occurs on the lateral side and is vulnerable to tears and to degenerative changes, as it becomes pinched during movements of the knee Symptoms usually appear at an earlier age than is the case in other meniscal lesions and require excision of the meniscus.

Cystic degeneration involves the lateral meniscus more frequently than the medial in the ratio of about five to one which is approximately the reverse of tears of a meniscus. Cysts of the meniscus sometimes follow a direct blow upon or a twist of the knee. They begin as a mucoid degeneration of the fibrocartilage of the meniscus resulting in the

Fig 125. Small cysts f rming lateral meniscus

Fig 126. Large cyst of lateral meniscus.

formation of multiple small collections of mucus which coalesce to form multilocular cysts (Fig 125) The larger cysts present in front of or behind the fibular collateral ligament and are more prominent as the knee is extended. Because of their origin within the meniscus, this entire structure should be removed together with the cyst. (Fig 126.) This is best accomplished by an incision such as described by Cave[2] which gives access to the entire meniscus, as well as an excellent exposure of the cyst.

OSTEOCHONDRITIS DISSECANS

Osteochondritis dissecans is a unique derangement of joints, most frequently affecting the medial condyle of the femur (Figs. 127 and 128) in which a segment of articular cartilage becomes separated from the remainder of the joint surface. Often this fragment remains loosely attached to the condyle by fibrous tissue until some minor injury dislodges

Fig 127 On left osteochondritis dissecans of medial femoral condyle On right: the same two years after removal of loose fragment, showing rthritic changes f medial rticular margi

Fig. 128. Osteochondritis dissecans of medial femoral condyle

Fig. 129. Microscopic section of loose body (see Fig. 128). On right, living hyaline cartilage. On left, necrotic cancellous bone. At bottom, fibrous attachment to bed in which loose body lay.

it from its bed, after which the piece of cartilage and bone becomes a loose body and causes recurrent momentary locking of the knee. This condition has been explained as an avascular necrosis of the segment of bone and cartilage. It is sometimes observed to develop several months after a contusion or twist of the knee has occurred, the roentgenograms taken immediately after the injury having been negative.

There is strong evidence that many of the instances in which a diagnosis of osteochondritis dissecans has been made in childhood are actually cases of irregularity of ossification of the distal femoral epiphysis, as recently described by Caffey, Madell, Royer and Morales. These authors report such examples in more than one half of the roentgenograms of the knee in 147 symptom free children. The condition disappears spontaneously after six to twelve months. The presence of loose bodies in craters in the medial femoral condyle was closely simulated in nineteen of the above 147 children. Other authors who have explored such knees in children for a supposed osteochondritis dissecans have often failed to detect any abnormality of the articular cartilage and have noted the return of the roentgenographic appearance to normal within five to nine months.

The diagnosis is readily made on the basis of roentgenograms. The treatment is the removal of the loose fragment and the excision of such degenerative cartilage as may be found together with the fibrous tissue which forms the bed of the loose body. The subchondral bone of this bed may then be penetrated with multiple small drill holes in the hope that granulation tissue will grow through these holes and eventually be transformed into fibrocartilage. Microscopic examination of the loose body usually shows three zones, with the superficial consisting of hyaline cartilage, the cells of which are living. Beneath this is an area of variable width composed of cancellous bone devoid of nuclei. The marrow spaces in this bone also contain no living cells. The third zone is a narrow band of dense connective tissue which apparently anchored the loose body to its bed (Fig. 129).

OSTEOCHONDROMATOSIS

Osteochondromatosis refers to the formation of multiple loose bodies (Fig. 130) most frequently in the knee joint, which are thought to arise from the synovial membrane by a metaplasia of connective tissue into cartilage and bone. These bodies are at first attached to the synovial membrane by a pedicle which preserves their blood supply. When such a body becomes detached and wanders freely

Fig 130 Osteochondromatosis.

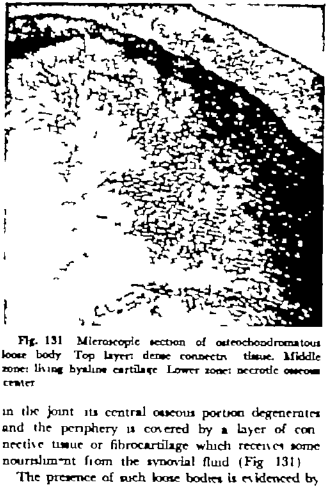

Fig. 131 Microscopic section of osteochondromatous loose body Top layer: dense connective tissue. Middle zone: living hyaline cartilage Lower zone: necrotic osseous center

in the joint its central osseous portion degenerates and the periphery is covered by a layer of connective tissue or fibrocartilage which receives some nourishment from the synovial fluid (Fig 131)

The presence of such loose bodies is evidenced by the occurrence of a repeated momentary locking of the knee joint and sometimes by the palpation of these bodies in the suprapatellar pouch. An effusion often follows the episode of locking Roentgenograms reveal those containing bone or calcified cartilage. The removal of the loose bodies should be performed as soon as their presence is known because

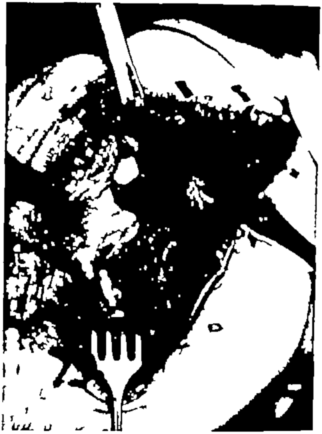

Fig 132. Loose body in suprapatellar pouch of osteoarthritic knee

the repeated episodes of locking will cause progressive degeneration of the articular cartilage. A median or lateral parapatellar incision gives the best exposure If the process of loose body formation is still active synovectomy is advisable

Other types of loose bodies arise from the separation of arthritic osteophytes from the margins of the joint (Fig 132) Such bodies may grow in size and their surfaces become smooth by the formation of cartilage about the original nucleus of bone Trauma may produce an osteochondral fracture of the patella or femur with a fragment becoming detached to form a loose body resulting in similar symptoms and requiring removal in order to relieve those symptoms and to prevent further damage to the articular surfaces of the knee

CHONDROMALACIA OF PATELLA AND FEMUR

The degenerative lesions of articular cartilage which result from acute trauma, from repeated minor injuries, or even from the process of wear and tear have long been recognized. Two hundred years ago, William Hunter remarked, "If we consult the

Fig. 133. Earliest stage of chondromalacia of patella.

standard Chirurgical writers from Hippocrates down to the present age we shall find that an ulcerated cartilage is universally allowed to be a very troublesome disease that it admits of a cure with more difficulty than a carious bone and that, when destroyed, it is never recovered."* This inability of articular cartilage to repair itself results from its lack of blood supply and from the fact that the cartilage cell is a highly differentiated type of connective tissue which has lost its power to revert to the embryonic type of tissue which is the basis for any reparative process. These degenerative changes in articular cartilage especially with regard to the patella have in recent years been designated as chondromalacia, in contradistinction to the various types of arthritis. The process of repair is not evident, there is simply a fibrillation of the superficial layers of hyaline cartilage which steadily progresses until the underlying bone is exposed in the more advanced cases. (Figs. 133 to 137) The central portion of the patella is most frequently involved and often a similar condition (the mirror image lesion) develops on the opposing surface of the femur In various large series of arthrotomies of the knee for internal derangements which have been reported, the incidence of chondromalacia has run as high as 50 per cent. Its frequency in such series probably depends upon the diligence with which it is sought. Any arthrotomy of the knee joint should employ an incision which is adequate to permit examination of the undersurface of the patella at least with the palpating finger

Some of the common causes of chondromalacia of the patella are instability of the patella (or recurrent subluxation) torn menisci and loose bodies in the knee joint The symptoms which usually result from chondromalacia of the patella include crepitations on movements of the knee a grinding sensation or momentary painful catch in the knee joint during walking (especially on stairs) a pain deep in the knee, and a subjective feeling of instability The examiner may note a palpable crepitus as the patella is rubbed over the surface of the femur in extension, together with tenderness which is commonly found along the medial border of the patella. As a rule, roentgenograms do not demonstrate this condition.

The type of treatment which is employed depends upon the degree of the chondromalacia. In the earlier stages, in which only the superficial layers of cartilage are involved, I excise the fibrillated and softened cartilage with a sharp scalpel or chisel and do not disturb the deeper layers or underlying

A.

B.

Fig. 134. Moderate chondromalacia of patella. A, Articular surface B, Side view to show crabmeat appearance

* From Hunter William On the Structure and Diseases of Articulating Cartilage Phil. T Roy Soc., London 9: 267 1743

Fig 135. Microscopic section of cartilage of patella showing the fibrillation of chondromalacia.

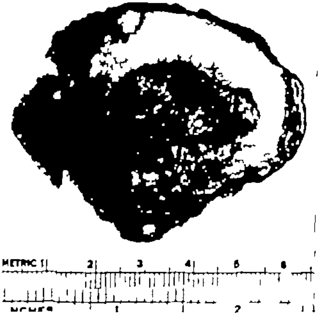

Fig. 137 Severe chondromalacia of patella.

Fig 136. Widely opened knee joint On left patella showing severe chondromalacia On right mirror image lesion on femoral condyles

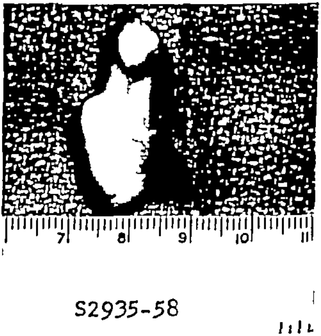

Fig. 138. Marginal osteochondral fracture of patella (excised fragment)

bone When the lesion has progressed to the point that subchondral bone is exposed over less than one half of the surface of the patella all degenerated cartilage is excised and multiple small drill holes are placed through the subchondral bone in the hope that connective tissue will grow through these holes and cover the raw surface with a dense fibrous tissue which is a fair substitute for articular cartilage Although this procedure has been carried out several times I have not had the opportunity to observe the surface of the patella at a later date a fact which may attest to the effectiveness of the treatment In those patients in whom the chondromalacia is more advanced a total patellectomy has usually been done with satisfactory results. In adults in whom extensive chondromalacia is found to have resulted from a recurrent dislocation of the patella a patellectomy procedure recently described by West and Soto-Hall is advisable.

Fig. 139. Large osteochondral fracture of patella. On right patella from surface of which osteochondral fragment has separated On upper right, osteochondral fragment On left, femoral condyles showing "mirror image" lesion.

OSTEOCHONDRAL FRACTURE OF PATELLA

An unusual internal derangement of the knee which may give symptoms simulating those of a torn meniscus or chondromalacia of the patella is an osteochondral fracture of the patella (Figs. 138 and 139) This may consist of a breaking away of a small marginal fragment which retains some attachment to the patella. In other patients, a considerable area of cartilage, with or without subchondral bone may be chipped away from the patella by a blow In such a case the friction of the raw surface of the patella against the femoral condyle may produce on it a mirror image lesion like that seen in chondromalacia of the patella. Depending upon the degree of involvement the loose fragment or the entire patella should be excised.

CONCLUSIONS

Because of its exposed position and its conformation the knee joint is subject to frequent injury and to wear and tear degenerative changes in its cartilage

Nearly all of the internal derangements of the knee joint are amenable only to operative treatment

Early diagnosis and prompt surgical treatment is essential for the prevention of permanent changes of this articulation.

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PART FIVE

THE SPINE

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DIAGNOSIS, TREATMENT, AND REHABILITATION OF THE INDUSTRIAL LOW BACK CRIPPLE

It is well known that the low back cripple presents an ever-continuing challenge to the medical profession. During the last three decades, great strides have been made in diagnostic techniques and the evaluation of the relationship of architectural and pathological abnormalities to the production of low back pain. A careful perusal of the vast literature which has accumulated on this subject will, nevertheless, attest to the fact that there are still in this subject many important areas of conflict of opinion by outstanding physicians of wide experience. But, even on matters of general agreement, the complexity of the problem may lead to errors in diagnosis and treatment which are often responsible for the futile management of these difficult cases.

While the causes of low back pain are legion only a few of the most common conditions encountered in industry will be considered in this discourse. Numerous pathological lesions capable of causing low back pain with or without sciatica, such as either primary or metastatic malignancies of the osseous or the nervous system as well as other diseases of the abdominal or pelvic organs, are of interest primarily from a diagnostic point of view. Their relationship to industry would ordinarily be purely incidental, and their treatment would be clearly established by the exact diagnosis. Fortunately for the industrial and orthopaedic surgeon these conditions do not introduce a formidable problem, and the medicolegal implications are usually easy to resolve.

POSTURAL CONDITIONS

Among the perplexing low back problems encountered by physicians are those of vaguely defined symptom complexes of postural origin. Strains of the architectural and kinetic structures of the lower back may result from any single or multiple factors which impose abnormal loads upon muscles and other soft tissues. They are frequently seen in cases of spinal curvature or other long-standing deformity imbalance due to inequality in the length of the legs, deformity of one or both legs with or without stiffness or loss of motion in one or more joints relaxed (hypermobile) spines, cases of sway back round back etc. Postural strains may result indirectly from flatfeet faulty shoeing high heels, short heel cords, etc. They may be induced by using slovenly habits while seated, improperly designed chairs, low overstuffed davenports, and even by faulty tilts or heights to automobile seats and other equipment requiring prolonged, continuous use by an individual. Where the symptoms are of *obscure origin without antecedent trauma* and are of a *vague variable nature the postural factor must be considered*. Backaches of this nature usually reveal their etiology in a *careful determination* of their relationship to the patient's pattern of activity or rest, they usually become progressively worse during the day or at night according to the cause and are relieved by the elimination, if possible of the adverse influence whatever it may be.

Postural backaches must be studied with a view

to overcoming any structural defects that are amenable to correction. A short leg can be made equal to a longer one with heel and sole lifts, spinal curves can be compensated overweight (causing swayback) can be reduced, selection of improper chairs, beds, automobile seats etc. can be revised and corrected. Strain can be minimized with orthopaedic belts and braces which exercise a favorable influence of one kind or another on posture saggy mattresses can be firmed with health boards (wallboard) under the mattress or replaced with equipment of suitable quality and construction. Improper chairs can be eliminated, avoided, or replaced with correctly designed furniture Persistent aching discomfort can be mitigated with deep heat (hot tub baths) and internal analgesics (aspirin, etc)

SENESCENT OSTEOPOROSIS

Osteoporosis of the spine represents another slowly evolving cause of low backache which may easily be overlooked particularly in its early stages. As Homburger aptly stated, "Osteoporosis passes unrecognized more often than most other chronic diseases has caused more pain than many of them, and is more amenable than any other to simple therapeutic measures."* This condition usually appears in individuals over 45 years of age and is about four times as common in women as it is in men. It generally occurs in individuals who have led a sedentary life, but it has also afflicted persons who have always been extremely active. The symptoms develop insidiously with a dull, widespread aching in the back which may continue without remission for months or years. Frequently after a slight strain or jar the patient will become conscious of an acute pain in the back which completely incapacitates him or her The pain may remain localized at the lower dorsal or lumbar region or it may radiate along the course of one or more nerves. Roentgenograms of the spine will reveal a "washed out" appearance of all the vertebrae ballooning of the discs in the lower dorsal and lumbar regions, with associated increased concavity of the vertebral end plates. The discs in the upper thoracic region are usually thinned, there is hyperostotic spurring at the anterior margins of the adjacent vertebrae and a kyphotic curve is usually present in the lower thoracic area All grades of disc swelling osteoporosis, and kyphosis, with or without herniation of disc nuclei into vertebral bodies or compression deformity of various vertebrae, may be noted.

While the exact etiology of senescent osteoporosis may still not be established on a scientific basis,[3] the fundamental feature of disturbed bone metabolism is nevertheless fully accepted A defect in the formation of bone matrix results in a deficiency of calcified bone. Estrogen-androgen imbalance senile metabolic changes, prolonged medication with ACTH or the cortisones, hyperthyroidism, diabetes, hypopituitarism, malnutrition, adrenal gland pathology and many other obscure factors may set up the condition which may progress insidiously for years before it can be recognized objectively Thus, it is obvious that the progression of the disease during its evolution bears little, if any relationship to the vocational activity of the individual, and its disabling symptoms and associated structural defects must, therefore be regarded as of nonindustrial origin. While it is true that acutely painful and disabling symptoms are frequently precipitated by some more or less minor incident, often occurring while the patient is on the job this condition merely represents the ultimate result of the underlying pathological process. Watkins[4] refers to this as "the last straw of stress" which "literally breaks the camel's back" and states that "spontaneous collapse of vertebrae is often observed in the senescent spine, attributable solely to this "last strain "

These patients seem to respond favorably to endocrine (estrogen androgen) therapy with moderate (corset or light brace) protection and a high protein, calcium, and vitamin diet. Although their subjective discomfort can thus be reduced or eliminated within three to six weeks bone remineralization is rarely observed, and they are always potentially hazardous as workers and frequently experience further acutely disabling episodes due to collapse of other spinal structures.

FRACTURES OF THE SPINE

While *spontaneous* collapse of vertebral bodies represents a nonindustrial disease and is of paramount importance from the point of view of diagnosis and its medicolegal implications, truly traumatic *fracture* of the spine presents an entirely different problem. In true or suspected crush fractures of the vertebral bodies occurring under circumstances of adequate traumatic force, the roentgenograms will readily rule out pre-existing osteoporosis and will generally establish clearly the presence of an acute or recent fracture. Often however even

* From Homburger F The Medical Care of the Aged and Chronically Ill, Boston, 1955 Little Brown & Co p. 14

Table 4 Differential Diagnostic Features of Fresh and Ancient Fractures and Congenital or Developmental Defects of Vertebral Bodies

Characteristic	Acute Recent Crush Fracture	Ancient Healed Fracture	Congenital Acquired Defect
1 Severe traumatic force usually hyperflexion type fall from height on feet or buttocks violent experience—automobile or other collision	Yes	Yes or No	Yes or No
2 Truncation or wedging of vertebral body	Yes or No	Yes	Yes
3 Wedging or compression upper portion of vertebral body only	Yes (in 99% of cases)	Yes	Yes or No
4 Wedging, upper and lower portions of vertebral body	No (in 99 of cases)	No	Yes (usually)
5 Zone of increased density in upper half of vertebral body	Yes	No	No
6 Forward protrusion, upper anterior corner of vertebral body	Yes (usually)	Yes (usually)	No (usually)
7 Thinning of disc above suspected vertebral body	No (usually)	Yes (usually)	No
8. Mushrooming laterally upper and lower corners of vertebral body	Yes (usually)	Yes (usually)	No
9 Calcification anterior longitudinal ligament	No	Yes (frequently)	No
10 Evidence of disc herniation through superior end plat	Yes or No	Yes or No	No
11 Tenderness to pressure and pain in suspected area on hyperflexion of neck, only (Soto-Hall sign)	Yes	No	No
12. Reduction by hyperextension possible	Yes	No	No
13. Fissure lines smooth and unchanging in course of time	No	Yes	Yes
14 Involvement of segments at dorsolumbar junction	Yes (70% D12 L2) (frequently)	Yes (70% D12 L2) (frequently)	No
15 Healing reaction during first three months revealed roentgenographically	Yes	No	No

where a deformed vertebra without related associated disease is noted, there may be some question as to whether or not the deformity is due to either a *recent* or an *old* compression injury or whether it is of ancient *congenital* or developmental origin. Aside from the matter of determining liability for a specific defect in a given case it is certainly important not to subject an individual with an old defect, with or without an associated soft tissue injury to all the prolonged restriction imposed upon one who has a true recent acute structural injury to a vertebral body

Differential Diagnosis of Fractured Spine. The differential diagnosis in such cases is, therefore, important, and the features presented in Table 4 have proved to be valuable in properly establishing the correct diagnosis.

It must constantly be borne in mind that many developmental defects such as Scheuermann's disease, Calvé's disease or vertebra plana, hemivertebra, limbus vertebra, spondylolysis, and unattached transverse articular and spinous processes, may simulate fracture. It is, therefore, important to have these conditions in mind before concluding that the mere presence of a structurally defective vertebra indicates a recent fracture. It is also well to remember that about 5 per cent of compression injuries of the spine are multiple and that frequently the two or more injured structures are separated by normal intervening segments. Routine roentgenography of the spine in suspected instances of fracture should include at least survey studies of the *cervical dorsal* and *lumbosacral* areas with special detailed studies, including laminagrams where necessary of the specific sites of injury

Fracture Treatment. Having definitely determined that a given structural defect is clearly of recent origin the exact nature of the treatment to be given must be considered. Although hyperextension of the spine for compression defects of the vertebral bodies was popularized by Davis[6] in 1929 and has subsequently become almost the standard form of treatment for these injuries, critical studies of end results with the use of this method have *recently* cast considerable doubt upon its efficacy Nicoll[7] *in 1949* reviewed 135 cases of spinal fracture two to five years after injury and concluded *that the functional* results following treatment with little *or no* external protection or attempted reduction were *"far superior"* to those in patients treated

by hyperextension reduction and plaster of Paris immobilization for three or more months. He postulated that (1) a good functional result is not dependent on a good anatomical restoration (2) consolidation is rapid even in the absence of fixation (3) the *important factor* in determining function is *stability between the damaged segments* not the position in which it is achieved and (4) prolonged fixation of damaged soft tissues, especially in their shortened position (hyperextension) is in itself a cause of disability Howorth[8] discussing the same problem stated "Whatever the method of correction the use of force may be dangerous, especially if there is a fracture of the posterior arch, rupture of the ligaments, or impending injury of the spinal cord or nerve roots. [He is] not convinced from his own experience or what he has heard or seen in the literature that any of these methods, as ordinarily practiced has resulted in significant correction of the deformity of the vertebral body in most cases."* Much of the correction is obtained through the discs of neighboring joints for full correction does not occur in the compressed body unless the spine is fully hyperextended in that area, and this is often difficult to accomplish and is ultimately lost in 94 per cent of the cases.

The greatest problem in severe or even moderate fracture is frequently not the fracture so much as the soft tissue damage. Excessive deformity producing articular disalignment and postural imbalance fracture of the posterior arch or the articular processes, severe ligamentous injury and dislocation, and late posttraumatic degenerative changes in the area of primary injury or in secondarily involved regions may result in chronic pain and disability Those patients with obviously severe initial injury or those who, because of severe and persistent pain, cannot be successfully rehabilitated justify spinal fusion. The decision concerning surgery should, however be approached guardedly particularly in litigative cases, and must rest upon clear evidence of adequate underlying defect or pathology

CHRONIC ARTHRITIS

Among the patients who challenge the resourcefulness of the industrial or orthopaedic surgeon and often persistently defy successful rehabilitation are those with chronic arthritis, usually of the degenerative type The underlying pathological process has usually been smoldering silently and insidiously for years when some minor incident may break through the fragile margin of safety and precipitate a painful reaction. Often an entirely normal motion or a stress no greater than the individual has sustained many times before without discomfort will become a "last straw" factor The ensuing pain will lead to muscle spasm, and one will sustain the other producing a chronically disabled state Roentgenographic study of such an individual's spine will reveal more or less advanced hyperostosis, degenerative thinning of discs and apophyseal joint spaces, constriction of neural foramina, and many other features of long-standing deterioration Obviously such an individual is not likely to recover quickly through any form of treatment and, even if he does recover from the first episode another one may soon follow The compensability or noncompensability of such a condition rests upon so many factors that each case must be evaluated individually

Much importance attaches to the actual degree or amount of trauma as a determining factor in the production of symptoms. If the forces involved are great enough to have been potentially capable of injuring a previously normal back, certainly the arthritic should not be denied judgment under the Compensation Act merely because nonsymptomatic degenerative changes in the spine are revealed by x-ray examinations. Often also the pathological changes noted in the roentgenograms may be purely incidental findings, and the actual cause of the disabling pain may be an entirely separate entity unrelated to that pathology I have often seen individuals with persistent low back disability whose roentgenograms showed widespread osteoarthritis and who were, accordingly regarded as incurable but who were nevertheless, rendered completely nonsymptomatic by a fusion across the vulnerable intervertebral space, usually the lumbosacral In these cases it is enlightening to try to ascertain the exact site and source of the pain if it is diffuse and cannot be localized, it is not likely to respond to target therapy whereas if it can be shown that it arises from one segmental level (disc or posterolateral joints) special treatment (usually fusion) directed to that site will be curative

SPONDYLOLYSIS AND SPONDYLOLISTHESIS

Of all the structural defects commonly found in the lumbosacral region *spondylolysis* with or with-

* From Howorth, M B Fractures of the Spine American Academy of Orthopaedic Surgeons, Instructional Course Lectures. Ann Arbor 1957 J W Edwards, vol. 14 pp. 64-90

out *spondylolisthesis* creates the most vulnerable sit uation. This usually bilateral defect in the inter articular portion of the fifth (or other) lumbar ver tebra(e) is now generally regarded as being of de velopmental origin and usually becomes evident in the roentgenograms in the last half of the first dec ade. Despite this early presence of the defect how- ever *symptoms* may not appear until the second or third decade and sometimes later. Some forward migration of the body of the involved vertebra is usually present, and the absence of a locking device at the posterolateral joints imposes an abnormal strain upon the disc and supporting ligaments, ulti mately leading to the development of more or less severe low back pain. Frequently as is observed in the arthritic spine, some minor incident will precipitate a major reaction and once such a reaction super venes (particularly if the circumstances under which it developed are compensable) relief is difficult to achieve through conservative means.

This obstinacy to treatment has been variously ascribed to abnormal mobility of the loose lamina which produces a downward pull on the first sacral nerve the presence of a fibrocartilaginous mass at the defect in the isthmus, narrowing of the intervertebral foramina, protrusion of the in tervertebral disc and stretching of the nerve roots and dura over the posterior edge and the body of the first sacral vertebra. Medicolegally a conflict of opinion is almost certain because the emphasis on the one hand is placed upon the inevitability of the disabling syndrome in the presence of the known architectural defect, while on the other hand the production of acutely disabling symptoms by the *"last straw" factor* receives the major emphasis. These cases, like others in a similar category must be evaluated individually taking all the facts and circum stances into consideration. Many of these patients have had previous episodes of a similar nature oth ers must obviously have been technically disabled on the basis of the extent of the architectural defect (even though they may deny previous symptoms) still others have been exposed only to minor trauma that could not significantly have influenced the low back condition. In another group however where the defect is relatively mild, the antecedent adaptive changes minimal and the previous record obviously devoid of disabling intervals, while the recent trau matic event was of a major nature the relationship of cause and effect would be clearly evident.

Although the painful recrudescence following industrial or other trauma may abate spontaneously or with conservative treatment in some of these cases, the experience with low back problems presenting this defect is *not good*. Usually the patient is aware or soon becomes advised of the presence of the struc tural defect an unfavorable psychological attitude toward the condition develops and the disability persists. In these cases after exhausting all conserva tive measures in a vain attempt to restore the indi vidual to his alleged nonsymptomatic state, surgical intervention is undertaken. The elimination of pain and the stabilization of an architecturally defective back of this nature is a formidable problem and must not be assumed lightly.

Surgery for Spondylolysis. While a number of technical procedures have been proposed for the relief of low back pain with or without associated sciatic radiation in cases of *spondylolysis* and spon dylolisthesis it seems generally agreed that the problem is a twofold one requiring both decompression (by removal of the loose lamina fibrocartilaginous mass, and protruding disc, if present) and stabiliza tion with fusion of the lower two or three lumbar segments to the sacrum. Because of the marked pre-operative and postoperative instability which is present, protection of these fusions is required for a considerably longer period of time than is necessary in the ordinary disc case. With careful management a preponderant majority of these patients can be im proved and at least half of them can be restored to their usual vocations.

INTERVERTEBRAL DISC SYNDROMES

Since clinicians have recognized the role played by the intervertebral disc in the production of low back and sciatic pain the overwhelming majority of disabled low backs have been ascribed to this condi tion. So much has already been said and written about this defection of the intervertebral disc that further discussion of the basic aspects of this problem is not necessary here. Because cases of this na ture are so common and frequently resist every type of conservative and surgical therapy some of the salient aspects of the subject as they relate to the low back cripple will however be considered. The first important fact to recognize is that an *inter vertebral disc may fissure or crack under almost any minor or major traumatic circumstance* and that, in fact, *many of them begin to disintegrate without any known trauma* except the usual wear and tear. *Once fissured or fractured spontaneous repair cannot oc cur and progressive disintegration inevitably super venes.*

Pain in the lower back is frequently present *without disc protrusion* and often such pain may be present before the roentgenogram discloses any thinning of its structure or associated evidence of reaction in the adjacent tissues. At this stage the defect in the disc can be established only with a discogram. When *protrusion* of disc material into the intraspinal canal occurs, nerve root pressure which sooner or later develops, leads to disturbed reflexes, pain, paresthesia, and motor weakness. *With conservative treatment* the edematous, protruded mass may recede or shrink markedly the inflammatory reaction will abate, and the compressed nerve may even slip off the underlying herniated mass.

This reversibility of the causes of radicular symptoms accounts for the characteristic remissions and recrudescences of disc syndromes but does *not* lead to a cure of the underlying defect. As Bosworth[10] has stated "*Permanent weakness* of the spine is present at the point of cartilage disruption *once disc laceration* has occurred. Such structural weakness remains and usually increases until and unless structural repair (that is, fusion) has been accomplished."* Barr[11] Compere[8] Bosworth,[9] and many others have contended that fusion should almost invariably *accompany* discectomy or decompression surgery on the lower spine, while still others[3] argue that fusion should be reserved for the relatively small percentage of patients who have had a discectomy but continue thereafter to have disabling low back pain. I concur strongly with those who favor the *combined operation* of discectomy with spinal fusion because it has been my experience that practically all individuals who have had a discectomy only sooner or later develop intractable low back pain. Certainly in the field of industrial surgery where most of these individuals require stable, pain-free spines, fusion seems to offer the best opportunity for the realization of such an objective.

INTRACTABLE LOW BACK PAIN AFTER TWO OR MORE SPINAL OPERATIONS

Perhaps the most disheartening group of patients are those who continue to have low back and/or sciatic pain despite the fact that they have already had two or more operations on the spine. Most neurosurgeons and orthopaedic surgeons have encountered some of these and all of them have been sorely tried to overcome the trouble. Ghormley[14] reviewed fifty four such cases seen at The Mayo Clinic and concluded that the problem was a most difficult one due principally to the presence of post traumatic and postoperative adhesions about the nerve roots, cauda equina, arachnoid or dura. Such adhesions could cause pain even in the presence of a solid fusion, and this pain was *rarely permanently eliminated* through further surgery. Psychoneurosis was an obvious factor in some of these cases and if it was associated with an organic cause for pain, remained *unresponsive to any form of therapy*.

Ghormley commented "We are of the opinion that surgical treatment has much to offer that a great many patients are satisfactorily relieved by such treatment, and that there will be many more who will be thus treated with satisfactory results. Failures will occur and some patients may need second operations to obtain relief much consideration should be given before advising a third operation, and as for the fourth and fifth operations, the indications would seem to be less and less definite for the failures will be more and more frequent."*

It is, therefore, obvious that multiple successive spinal operations should be done only on the clearest of indications.

SURGERY FOR LOW BACK PAIN OF DISCOGENIC ORIGIN

Despite the wide diversity of opinion concerning the indications for surgery and its exact nature in intractable disabling low back conditions, certain conclusions based upon the vast experience that has already been accumulated can safely be postulated. Whoever undertakes this type of surgery whether he be a neurosurgeon or an orthopaedic surgeon, should be thoroughly qualified by training and experience to cope with any type of lesion which he might expect to encounter in the intraspinal canal and *to perform all phases* of the operation. While many large clinics often utilize the neurosurgeon and the orthopaedic surgeon jointly in these operations, particularly if simultaneous fusion is contemplated many orthopaedic surgeons[3] decry the use of a neurosurgical-orthopaedic team and contend that whoever operates on a lacerated or herniated disc should repair the structure for stability and future

* From Bosworth, D M Surgery of the Spine American Academy of Orthopaedic Surgeons, Instructional Course Lectures, Ann Arbor 1957 J W Edwards, vol 14 pp 39-55

* From Ghormley R. K. The Problem of Multiple Operations on the Back, American Academy of Orthopaedic Surgeons, Instructional Course Lectures, Ann Arbor 1957 J W Edwards, vol. 14 pp 56-63.

weight bearing function with fusion as well as do the surgery relieving pressure It would seem reasonable in the light of the fact that *intraspinal adhesions* represent the most common cause of unsatisfactory surgery in this area, *that prime consideration* be given to the *avoidance of trauma in the intraspinal canal* before and during surgery Myelograms should be restricted to doubtful diagnostic situations, and the radiopaque material should be removed as completely as possible discograms should be undertaken only on the basis of special indications and should be performed exclusively by individuals who have perfected the technique of this delicate procedure

At the time of surgery approach to the intraspinal canal should be made wherever possible through the interlaminal spaces with minimal removal of marginal bone The surgeon should have a large selection of Kerrison type rongeurs of all sizes and shapes so that the decompression can be performed as adequately as necessary without injury to the dura This phase of the operation must be done with the greatest care because often extradural fat is absent and adhesions are already present between the dura and the ligamentum flavum and laminae. If the dura is inadvertently ruptured, it should be sutured as soon as the rupture becomes technically accessible with fine silk fused to special needles. During the exploration of the intraspinal canal the dura and nerves should be handled with extreme gentleness, and removal of protruding or herniated disc material should be performed as expeditiously as possible. Gauze packs, *Gelfoam, and other foreign material should* be kept out of the intraspinal canal because their use is conducive to scarring Bleeding should be controlled with suction and small muscle packs, the latter being left *in situ as required to protect the dura* and nerve roots, particularly if fusion is also to be undertaken

The ultimate achievement of a successful fusion re is basically upon the development of an aggressive healing reaction in th area to be bridged This renders mandatory the thorough curettage of all skeletonized areas and careful decortication (with suitable gouges) of all bone making contact *with the* grafts. The introduction of metal or any other foreign material into the area of fusion has *not* proved beneficial and in most instances has led to complications necessitating its later removal. Fresh, autogenous bone is far superior to bank bone and intimate contact of the transplanted with the host bone is always essential Whether one uses cancellous bone, locking or cortical onlay grafts is a matter of individual preference my own personal choice is cancellous bone as a binding medium (from the proximal tibial metaphysis) abetted by two sturdy cortical *grafts* also from the tibia, of suitable length and width to provide strength, stability and a roentgenologically demonstrable fusion mass (to satisfy critical appraisal in medicolegal cases) All this graft*ing material* should have close contact with the spinous processes, laminae and posterolateral joints which have been exposed and freshened to stimulate arthrodesis. It has been my custom routinely to *decompress* and explore *the fourth* and fifth lumbar interlaminal spaces removing protruding or significantly *bulging masses from the ventral wall with* a small circular incision around the mass and a pituitary *rongeur After preparing* the graft bed from L4 to S2, inclusive, and pressing the cancellous and cortical grafts into position, the protruding tips of the fourth and fifth lumbar spines are rongeured away *as is the entire spinous process of* L3 The last of these is sacrificed to provide additional grafting material to fill all crevices around the cortical grafts and eliminate the third lumbar spinous process as a *potentially impinging structure against* the fused subjacent mass. Finally the lumbosacral muscle masses, fascia, subcutaneous fat, and skin are firmly closed in layers with interrupted chromic catgut to the *deep tissues and cotton to the skin.*

Postoperative Care. Following surgery the patients are kept flat in bed for ten days then the sutures are removed and a torso Castex cylinder is applied from the mid-chest to the groins This cylinder is applied with the patient either prone or supine according to the preoperative situation which may need correction. Wherever possible, I try to restore a normal lumbar curve because *I have found that this* establishes better spinal balance and reduces or eliminates later postural strain. After the end of the second week the patients are allowed to be up for *from two to four hours* a day *until the end of the* sixth week when the active time is *progressively* increased At the end of three months, patients are *fully* ambulatory with the cast split down the front *for temporary removal* during periods of increasing duration daily *Through the fourth* month in the average disc case and the fifth month in spondylolysis cases, the patient is gradually weaned from the *cast. The average* patient is ready for supervisory or office work after four months, light work after five to six months, and heavy labor (unrestricted activity) after eight months. Standing anteroposterior

and lateral roentgenograms are made of the lumbosacral region at the end of three months, and bi plane motion roentgen studies are made at the end of eight. Usually these patients are ready for a terminal medicolegal appraisal eight to twelve months after their operation

ROUTINE MANAGEMENT OF LOW BACK CASES

The great importance, economic significance and potential seriousness of all low back injuries warrant the most careful approach in all instances. Any episode which causes immediate discontinuance of work or which persists to a significantly disabling extent for more than a few days demands careful study All too often the *eventual* thorough study of an intractable and disabling low back condition which did not receive detailed examination when it first developed has made it difficult to establish clearly the relationship between the late technical findings and the original injury Therefore, in these cases a careful history a complete physical examination with particular reference to the lower back, and x-ray study of the lower back and other regions, where indicated should be made and recorded without delay This initial investigation will generally indicate the nature of the problem will reveal the presence or absence of underlying pathological or architectural defects will disclose whether the situation is a primary or recurrent one, and will to some extent indicate the patient's attitude toward his condition and the degree of cooperation that can be expected of him in its management. In the uncomplicated or first attack situation complete rest at home or in a hospital localized protection, deep heat, internal analgesics and avoidance of recurrent strain till the pain subsides will generally quickly resolve the problem In purely traumatic strain of the musculoligamentous structures of the lower back, recovery within a matter of weeks can be expected. Following elimination of the pain, function must gradually be restored by progressive activity and exercises.

SPECIAL MANAGEMENT OF INTRACTABLE CASES

Patients who *fail* to respond to adequate conservative management for a *month* or *two* must be suspected of having some significant underlying pathological or architectural defect which will require definite management These cases warrant special study for a thorough reappraisal of the entire problem so that the cause or causes of the patient's failure to respond in the expected manner to the therapy provided can be determined. The scope of this study must, of course be customized to the particular situation at hand and may ultimately include all the physical psychological social and economic factors which are well known to participate in these matters. If constitutional contributory or sustaining factors are present, these must either be mitigated eliminated, or accepted, and the patient's future course charted accordingly The social and economic aspects of the situation must also be weighed in planning the further management of the case. Frequently the psychological attitude of the patient is completely incompatible with the objectives being sought by the physician If this is the case it should be recognized as soon as possible and every effort made, through sympathetic consideration, tact, and patient but firm management, to channel the patient into a more cooperative state of mind and early rehabilitation. The established patterns of disease or injury must be distinguished from the irregular allegations and often bizarre symptom complexes offered by the patient and motivated by a desire to achieve profitable objectives. Psychoneurosis of traumatic origin is said not to have appeared as a clinical entity until the latter part of the nineteenth century The almost simultaneous appearance of this ailment in Europe and America at that time can reasonably be correlated with the *existence of insurance* Many students of *psychoneurosis* state that it may *follow trauma* but is *not caused* by it. Since the introduction of industrial compensation acts in the United States in 1911 disability of functional origin has been increasing progressively while that of a structural and clearly objective nature has remained static. Thus, as Kessler[1] has so convincingly established "*the compensation system [itself] must be indicated as the etiological factor responsible for the prolongation of symptoms and the production of the neurotic behavior on which the prolonged disability is based* [italics mine]"*

While many experts in this field advocate broad study of these problems by medical specialists, psychologists, social workers, vocational educators, employment counsellors, private welfare agencies, government officials employers, insurance companies, and unions, it nevertheless appears to be a well-established fact that rehabilitation of these indi

* From Kessler H H : Low Back Pain I Industry New York 1955 Commerce & Industry Association of New York Inc

viduals commonly does *not* occur until the litigation has been *resolved*. This relative futility of rehabilitation in the presence of an adverse psychological attitude maintained by an underlying economic motive was recently discussed by Mork,[17] a consultant to California's Bureau of Vocational Rehabilitation, who stated that only 1 per cent of the workers applying for disability benefits under the Social Security Act are accepting and utilizing the services made available through state and federal sources to restore them to productive employment.

MEDICAL RATING OF PHYSICAL IMPAIRMENT

Because of the great complexity of disability evaluation and the numerous and diverse methods which have been devised and are now being utilized in these determinations, the president of the American Medical Association in 1956 appointed a Committee on Medical Rating of Physical Impairment. As a consultant to this committee I have had the opportunity to participate in the development of its *Guide to the Evaluation of Permanent Impairment of the Extremities and Back.*[1] This guide provides authoritative material to assist the physician in competently fulfilling his particular responsibility in this field, namely, the evaluation of permanent impairment. This guide defines *permanent disability* as a "*not purely medical condition*" and states that a patient is "permanently disabled" or "under a permanent disability" when his actual or presumed ability to engage in gainful activity is reduced or absent because of "impairment," and no fundamental or marked change in the future can be expected.

Permanent impairment, on the other hand, is a *purely medical condition*. *Permanent impairment* is any anatomical or functional abnormality or loss, after maximal medical rehabilitation has been achieved, and which the physician considers *stable* or *nonprogressive* at the time evaluation is made. It is always a basic consideration in evaluation of permanent disability. It should be remembered, however, that permanent *impairment* is a contributing factor to, but not necessarily an indication of, the extent of a patient's permanent *disability*.

Evaluation (rating) of *permanent disability* is an administrative, not medical, responsibility and function. Evaluation of permanent disability is an appraisal of the patient's present and probable future ability to engage in gainful activity *as it is affected by nonmedical factors* such as age, sex, education, economic and social environment, *and the medical factor permanent impairment*. Nonmedical factors have proved extremely difficult to measure. For this reason *permanent impairment* is in fact the *sole* or *real criterion* of permanent disability far more often than is readily acknowledged. *Evaluation* of permanent impairment forms the basis for a *determination* of permanent disability, which is an administrative decision as to the patient's entitlement.

The Physician's Role. Evaluation of permanent impairment defines the scope of medical responsibility and therefore represents the physician's role in the evaluation of permanent disability. Competent evaluation of permanent impairment requires adequate and complete medical examination, accurate objective measurement of function, and avoidance of subjective impressions and nonmedical factors such as the patient's age, sex, and employability. The major and practically exclusive emphasis in determining permanent impairment is placed upon impaired *function* as measured with a goniometer, and this applies to the spinal column in the same objective manner as it does to the extremities. The guide is a masterpiece of objectivity and only incidentally includes the loss of structural integrity, pathology, or pain when any or all of these are reflected in function. It must be recognized that this guide to the measurement of physical impairment purports to be *only* what it is designated, namely, *a guide*. The 1958 manual covers only joint function, which, of course, is only one aspect of the measurement of impairment. Future contributions to this subject must necessarily include many other features, such as deficiencies in muscle and bone integrity and strength, sensory, neuromotor, and trophic function, the vascular system, subjective pain, etc. Physical impairment is a composite of multiple factors and only by determination of the deficiencies of the total structure can it be accurately appraised.

Spinal Column Values. The entire spinal column has a total value of only 60 per cent of the value of the body as a whole, and each section of the spine, cervical, dorsal and lumbar, carries a fixed maximal percentage value of the whole spine, namely, 40 per cent for the cervical, 20 per cent for the dorsal, and 40 per cent for the lumbar. Despite this, however, fractures and dislocations of vertebrae *in any part of the spine* carry identical values, although ankylosis of two or more vertebrae carries rather widely divergent values, depending upon whether it is in favorable or unfavorable position. The disability resulting from restriction of spinal motion is evaluated in only two areas, namely, the cervical and

the dorsolumbar. Each normal motion in the neck and dorsolumbar area has an assigned value, and reduction of this motion rates a disability value depending on the degree. The accepted *normal* range of motion in the schedules is so modest that minor restrictions of motion in individuals of average architectural characteristics are *not* likely to qualify for any disability.

Intervertebral disc lesions begin with a minimum impairment allowance of 5 per cent of the whole man where *no significant residuals* are noted, to which is added further components for ankylosis, restricted motion in the spine or extremities, or other abnormal features. All disabilities or impairments are computed separately in relation to the spine itself or the man as a whole, according to the basis for each factor set forth in the table provided, after which the multiple elements of disability thus established are *combined* (not added) progressively also by the use of a table. Finally all the factors are reduced to a common denominator with regard to the man as a whole, thus establishing what purports to be the percentage of impairment arising from residuals in the spine of that subject. A clear comprehension of the usefulness of this guide in the evaluation of permanent impairment will of course require careful study of the instructions for its use and the utilization of all the tables of which it is composed. The Committee* which formulated it believes that "as one becomes acquainted with this material its simplicity and uniformity of application becomes readily apparent. Periodic review (and revision) will be necessary to assure the guide's continuing value as advances in medical knowledge and technique occur."*

Because the economic aspects of disability determinations are ultimately legislative and administrative devices, the physician can act only in an advisory capacity to those who are empowered to determine loss of working or earning capacity. All this has too long been subject to manipulation by pressure groups and juridical tribunals. The abstract, intangible, and purely functional aspects of disability have unfortunately gained the ascendency and what was originally intended to be a *boon* to the injured worker has become a *boomerang*. Unduly prolonged periods of disability for conditions of known average duration and the abnormally high incidence and progressive increase of functional conditions as contrasted with clearly objective ones have caused economic losses to workers far in excess of their gains. As Kessler[*] has said, "The money incentive behind Workmen's Compensation and the failure of all those who participate in its operation to visualize its true objective to *reduce* the period of incapacity and quickly and fully restore the worker to his job are the blights that produce all these problems."* The careful, skillful, and enlightened management of the low back cripple will accomplish much to mitigate or overcome the innumerable difficulties commonly encountered in this field.

* From A Guide to the Evaluation of Permanent Impairment of the Extremities and Back by the Committee on Medical Rating of Physical Impairment of the American Medical Association supplement to J. A. M. A., Feb. 15, 1958.

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FUNDAMENTAL PRINCIPLES AND TREATMENT OF SCOLIOSIS

A knowledge of the basic principles of scoliosis is necessary for the proper treatment of this condition. A normal spine is straight in the anterior posterior view In a newborn infant the lateral view of the spine is practically straight, but soon after birth, *cervical and lumbar lordoses and a dorsal kyphosis* develop as a normal physiological occurrence. Why does nature change from a spine which is straight to one that is curved? The reason is obvious! If the head were placed on a rigid continuous column, any jarring such as that which occurs in walking running etc would be directly transmitted to the head. Nature has set up a simple mechanism to overcome this. It has segmented the continuous spinal column *and placed shock absorbers (intervertebral discs)* between each segment. It has also provided an additional cushioning effect by bending the spinal column (kyphosis and lordosis) which acts as a spring The kyphosis and lordosis are present in the normal spine for the same reason that automobiles or trucks have springs for smoother riding

ANALYSIS OF CURVES

The anterior posterior curves of the normal spine are physiological, whereas lateral curves are pathological. The engineering principle pertaining to a bent rod namely eccentric loading efficiency increases with deflection, also applies to any curvature either physiological or pathological, of the spine In simple terms, it states that the more the rod is bent or curved, the easier it is to further

Scoliosis may be noted at birth or sometime during the growth period.

Compensation. It is my interpretation as illustrated in Fig 140 that the body is in balance and compensated when the shoulders are symmetrically placed above the pelvis and the head is held erect over the mid-sacral region. In this instance, the angular deviation of the spine in one direction will be equal to the angular deviation in the opposite direction.

To simplify a complicated subject as much as possible for the present, let us assume that we are dealing with scoliosis problems in which there are no deforming elements below the pelvic crests. *Correct analysis of scoliosis will however require* an evaluation of the patient as a whole in the standing position.

Assuming that the body is in compensation, the simplest form of scoliosis consists of three curves. In Fig 141 the middle curve, *P* is the primary curve or the area in which the deforming factor is active. The primary curve is the one which has to be included in the fusion area. The external configuration of the primary curve is always, or nearly always, a true arc or a so-called full curve. The two end curves, *F* and *F* are secondary and fractional they are attempting to return the spine to the erect position It is necessary that there be a fractional curve

d below a full curve in order to obtain

co

Curves. In order to treat scoliosis, it

is necessary to evaluate the curves as to both their extrinsic and their intrinsic properties. Extrinsic properties indicate the external configuration or shape of the curve. As mentioned, there are two terms, "full" and "fractional," which apply only to the configuration or shape of the curve and not to the elements within the curves.

A full curve is a segment of a true or nearly true arc therefore, it cannot return the spine to the erect.

A fractional curve is one that returns the spine to the erect, and, therefore, it is not a true arc.

In Fig 142 you will note one additional curve *S* interposed between the primary and the lower fractional curve. This is the so-called secondary curve. For the sake of simplicity instead of using the terms "secondary full" or "secondary fractional," I shall refer to them just as secondary or fractional. The deviation past the midline is necessary in order to compensate for the magnitude of the primary curve. When a secondary curve crosses the midline it nearly always takes on structural changes.

The intrinsic properties refer to the variations or limits of the angle of the curve which are obtained by bending the spine in a lateral direction, either actively or passively On the basis of the variations of the intrinsic properties of the curves, three types are evident structural, functional and mixed.

A structural curve is one which has intrinsic changes of acquired or congenital origin, such as abnormal rotation, wedging tilting gross malformation, and/or contracted soft tissues. Some or all of these elements are always found in a primary curve.

A functional curve is one which is similar to or like that seen in a normal spine on lateral flexion. It implies that there are no intrinsic changes and it will correct completely when the extrinsic, or outside, deforming forces are completely removed.

A mixed curve is one which has some degree of both functional and structural elements, and because of these characteristics it usually can also be classified as compensatory

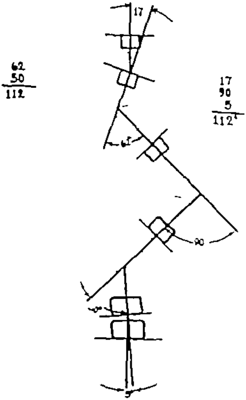

Fig 140. Demonstrating that when the body is in balance and compensated, the angular deviation on one side is equal to the angular deviation on the other (From Schmidt, A. C. Verhandl. deutsch. orthop. Gesellsch., 41 Kongress, pp. 195-220 1954 Ferdinand Enke Verlag Stuttgart.)

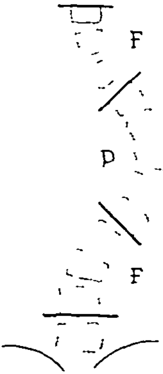

Fig 141 The area represented by P is the primary curve and the one in which the deforming factor is active. F and F represent the two secondary fractional curves, which are attempting to return the spine to the erect. (From Schmidt, A. C.: Verhandl. deutsch. orthop. Gesellsch., 41 Kongress, pp. 195-220 1954 Ferdinand Enke Verlag Stuttgart.)

An analysis of the structural, mixed, and functional curves on the basis of passive and active bending will reveal that the structural curve will correct the least, the functional curve completely or nearly so, and the mixed curve somewhere in between.

According to Ferguson,[8] "A primary curve is a *lateral structural curve resulting from a force acting contrary to the law of balance.*"[8] As stated before the structural curve is the one which has intrinsic changes. A primary curve may or may not also contain some functional elements, but these are of minor importance.

A secondary curve is one that compensates for a primary. It functions in accordance with the law of balance. It attempts to return the spine to the erect. A secondary curve may be purely functional, having no intrinsic changes, or it may be mixed, with some degree of both functional and structural elements.

A. Primary
 1. Does not function according to the law of balance
 2. Structural

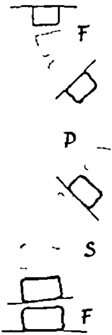

Fig. 142. Note the additional curve S, interposed between the primary and the fractional curve representing a secondary full curve. (From Schmidt, A. C. Verhandl. deutsch. orthop. Gesellsch. 41 Kongress pp. 195-220. 1954. Ferdinand Enke Verlag Stuttgart.)

B. Secondary
 1. Does function according to the law of balance
 2. May be entirely functional
 3. May be mixed—partly structural and partly functional

In Fig. 143 you will note four rectangular figures, *A, B, D* and *E* representing unrotated vertebrae. The trapezoid figure *C* represents a rotated and wedged *vertebra, indicating structural changes.* It has maximum rotation and is the most horizontal. We usually refer to this as apical rotation.

The vertebrae at the junction of the two curves, *B* and *D* are the least rotated and the most tilted. The remote end vertebrae of a scoliotic curve, *A* and *E* are the least rotated and usually approach the horizontal.

Primary and Secondary Curves. In cases of long standing, secondary curves usually reveal some struc-

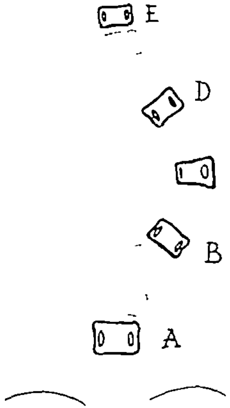

Fig. 143. Curve B-D represents the primary curve; curves D-E and A-B are fractional. Vertebra C is at the apex of a full curve and has maximum wedging and rotation. Vertebrae B and D at the junction of the two curves show maximum tilting and neutral rotation. Vertebrae A and E are at the terminal ends of the scoliotic curve and show no rotation, and their terminal surfaces are parallel. (From Schmidt, A. C. Verhandl. deutsch. orthop. Gesellsch. 41 Kongress, pp. 195-220. 1954. Ferdinand Enke Verlag Stuttgart.)

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[8] From Ferguson, A. B. Roentgen Interpretations and Decisions in Scoliosis. American Academy of Orthopaedic Surgeons, Instructional Course Lectures. Ann Arbor 1950, J. W. Edwards, vol. 7 pp. 160-167.

tural changes. In these cases, it may be difficult to determine which curve is the primary and which is the secondary. Frequently but not always, the primary curve, or the one wherein the deforming factor is active may be determined by the use of Ferguson's criteria.[14]

In the case of three curves, the middle one is usually primary. The greater curve or the one toward which the trunk is shifted is the primary. In this case (Fig 144 *A*) the primary measures 57 degrees, whereas the other two measure 28 and 31 degrees, respectively.

In Fig 144 B the curve with the least flexibility and correctability is the primary. The upper fractional curve corrected from 28 to 23 degrees, and *the lower from 31 degrees to practically neutral.*

The middle curve in Fig 144 *C* corrected from 57 to 34 degrees. In this instance the percentage of correction of the primary was greater than usual.

The lateral bending test is a passive form of correction, and the information sought is how much the primary curve or curves can be corrected in preparation for fusion.[7] In this normal spine (Fig 145 *B*) you will observe that the lumbar area flexes laterally more readily than the dorsal. There is also a trace of rotation in the lumbar area, none in the dorsal. It will aid in identifying and determining the excursion of the secondary and fractional curves,

A B C.

Fig 144 A. In this roentgenogram taken *of a patient in the standing position, D5 to* L1 inclusive is the middle the maximum, and the primary curve. The trunk is shifted slightly to the right. B, A film taken in the supine position, shows the patient bent in order to determine the flexibility of the curves D2 to D4 inclusive and *L2* to *L4* inclusive. It is not unusual for a short upper dorsal curve to become fixed, even though it is a secondary curve, due to the deformity of the short ribs. C, A roentgenogram also taken in the supine position, shows the patient bent to determine the flexibility of the curve *D5* to *L1* inclusive. Percentage-wise the secondary fractional curve *D2 to D4 inclusive* corrected less than D5 to L2 which is presumed to be the primary curve, again demonstrating the rigidity of an upper dorsal curve of long standing. (From Schmidt, A. C.: Verhandl. deutsch. orthop. Gesellsch 41 Kongress pp 193-220 1954 Ferdinand Enk Verlag Stuttgart.)

upper and L1 is the lower end vertebra of the complete curve. Frequently an unrotated vertebra is not in evidence. It is then desirable to choose the adjacent vertebra distal to the curve being measured, even though it is rotated away from the concavity

The method of measuring a primary curve is as shown. To measure the angle of deflection or angle of the curve, as it is commonly called, erect intersecting perpendiculars from the superior surface of the upper end vertebra and also from the inferior surface of the lower end vertebra, D9 to L1 respectively The angle formed by the intersection of these perpendiculars is the angle of the curve. The curve in this diagram measures 90 degrees.

The remaining curves are measured in a similar manner with one exception. When the adjacent curve is measured, a continuation of the perpendicular used for the previous curve will serve as one of the perpendiculars. The intersection of this line with the distal perpendicular constitutes the angle of the curve being measured. One should measure the scoliotic curve as a whole, not just separate segments of it. Do not disregard the intervertebral spaces between the curves, which, as a rule, present some wedging

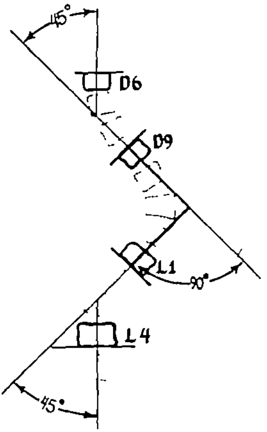


Fig 148. Diagrammatical drawing showing the measurement of a complete scoliotic curve. (From Schmidt A. C. Verhandl. deutsch. orthop Gesellsch., 41 Kongress, pp. 195-220, 1934 Ferdinand Enke Verlag Stuttgart)

Pelvic Tilt. When analyzing scoliosis with a pelvic tilt, assuming that there is no deformity below the iliac crest, four different possibilities should be considered.[8]

First, when the pelvis is high on the concavity of the lumbopelvic curve (without a lower fractional curve) that curve is then primary (Fig 149 *A*)

Second when the pelvis is high on the concavity of a short lumbopelvic curve (Fig 149 *B*) this curve is also primary if the curve above is minor or fractional. If the sacrum is part of the major curve, the tilt of the pelvis will then be approximately equal to or more than the tilt of the adjacent vertebra.

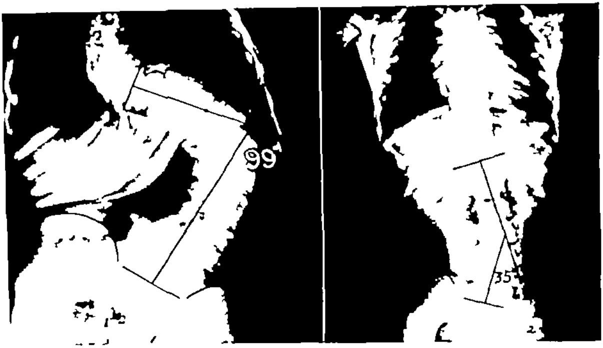
Third, when the curve above is of great magnitude and the pelvis is high on the concavity of the short lumbopelvic curve (Fig 150 *A*) then the latter curve is not primary In order to obtain balance, this patient has to stand with the pelvis elevated on the side of the major curve.

Fourth, when the pelvis is high on the convexity of the lower fractional curve (Fig 150 *B*) the encroachment of the above adjacent curve prevents the pelvis from assuming a horizontal position. In this particular situation, the fractional curve is almost never primary

When there is a fractional curve located between a moderately severe to an extremely severe lumbodorsal curve and a horizontal pelvis (Fig 151) the short lumbopelvic curve is never primary

Good results are most difficult to obtain when the pelvis is tilted and the lowest curve is a primary because of the fact that this usually requires fusion down to and including the sacrum. Correction and fusion of the primary curve when the pelvis is tilted and the lower curve is compensable frequently is not warranted because of marked structural changes in the compensatory curve, limiting the amount of correction. Overcorrection may result in a pelvis tilted in the opposite direction.

Minimum, Maximum, and Actual Fusion Areas. The minimum fusion area, or "measured curve," is determined by a standing roentgenogram before correction is obtained (Fig 152) It is clearly defined when the junction of the primary and secondary curves present a neutral vertebra which has at one level maximum tilting with the least rotation and wedging of the intervertebral spaces above and below in the opposite directions.



A. B.

Fig. 149 A, When the pelvis is high on the concavity of a lumbopelvic curve (D9 to L5 inclusive) that curve is always primary B, The same is true particularly when the curve above (D12 to L5 inclusive) is minor or fractional. (From Schmidt, A. C., Verhandl. deutsch. orthop. Gesellsch., 41 Kongress, pp. 195-220 1954 Ferdinand Enke Verlag Stuttgart.)

A. B.

Fig. 150. A, When the curve above is great, the short lumbopelvic curve (L3 to L5 inclusive) is not primary B, When the pelvis is high on the convexity of the lower fractional (L4 to L5 inclusive) this fractional curve is almost never primary (From Schmidt, A. C.: Verhandl. deutsch. orthop. Gesellsch., 41 Kongress, pp. 195-220 1954 Ferdinand Enke Verlag Stuttgart)

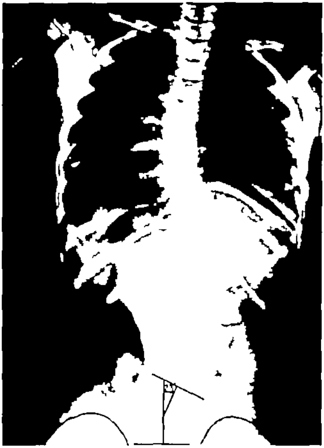


Fig. 151 This fractional curve (L4 to L5) located between a moderately severe lumbodorsal curve and a horizontal pelvis, as shown on the roentgenogram, is never a primary curve. (From Schmidt, A. C.: Verhandl. deutsch. orthop. Gesellsch., 41 Kongress, pp. 195-220 1954 Ferdinand Enke Verlag Stuttgart.)

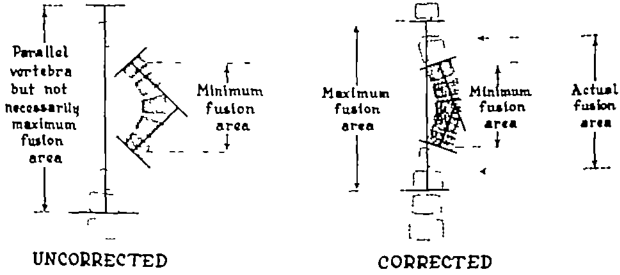


Fig. 152. The minimum, maximum, and actual fusion areas. (From Schmidt, A. C.: Verhandl. deutsch. orthop. Gesellsch. 41 Kongress pp. 195-220 1954 Ferdinand Enke Verlag Stuttgart.)

The three elements which determine the end of a curve especially a rapidly developing one, as in poliomyelitis, are not frequently found at the same level. Rotation occasionally is absent entirely. Rotation makes its appearance first at the apex of the curve and then spreads distally in both directions. This is known as rotational lag. Maximum tilting is usually found near or at the true junction of the curves. Wedging of the intervertebral spaces may be slight. When fusion is indicated in a curve in which the limits have not been definitely established the minimum fusion area should include the longest segment defined by any one of the three elements. In most instances, the proper choice of the area to be fused will be from parallel to parallel (the maximum fusion area).

When in doubt about the length of the fusion area, it is wise to include one or more vertebrae above and below. This is particularly true of the lower fusion area unless there is a short fractional curve between the fusion area and the sacrum.

The maximum fusion area is from parallel to parallel vertebrae as seen on the roentgenogram after the curve has been corrected as far as possible or desirable. For correct analysis vertebrae are considered parallel only when the end vertebrae are perpendicular to the same line and this line passes through the centers of both vertebrae. There are rare exceptions when you choose to fuse beyond the parallel vertebrae. In general the exception occurs when fusing two primary curves or when extra vertebrae are added to the fusion area in order to obtain compensation.

Forces Used in Correcting Scoliosis. In Fig. 153 *A* D9 to L1 represents the primary curve whereas D3 to D9 and L1 to L4 represent secondary curves. D3 and L4 are horizontal and are the remote end vertebrae of the entire curve.

In Fig. 153 *B* the scoliotic curve has been corrected by the forces of symmetrical distraction derotation and lateral pressure, as incorporated in the Milwaukee brace or localizer jacket. Both secondary

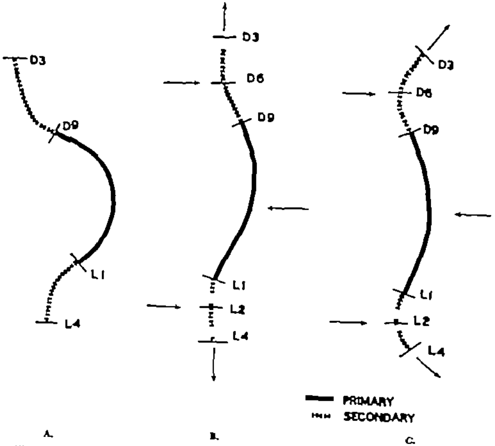


Fig. 153. A represents a simple scoliotic curve in the standing position. B indicates that, by using symmetrical distraction and lateral pressure both the primary and secondary curves are corrected. C demonstrates that the secondary curves are increased by attempting to correct the primary through the use of a turnbuckle jacket.

and primary curves are corrected by the application of these forces. D6 and L2 represent the closest parallel vertebrae. Since the patient is maintained in compensation while correcting the scoliosis, fusion beyond the parallel vertebrae will not alter the compensation. A long fused column will enhance compensation.

Fig 153 *C* represents the application of the forces used in a turnbuckle jacket. D6 and L2 represent the nearest parallel vertebrae. In this form of correction, the secondary curves are increased while correcting the primary. Fusion beyond the nearest parallel vertebrae may result in the patient being fused off balance. It is reasonable to assume that by increasing the pressure on the concave side of the secondary curve over a period of months, epiphyseal growth will be retarded on that side. By the same token Risser and associates [8] have shown cases in which, when pressure was released on the concave side of the curve, the wedged vertebrae again assumed their rectangular outline.

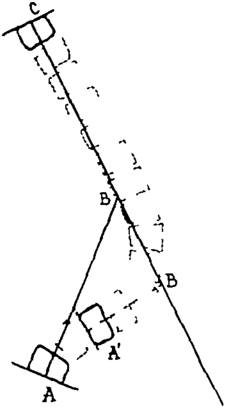


Fig 154 This diagram of spine indicates a curve A'B'C, that is unbalanced, according to former analysis. Vertebra A is chosen for balance so that AB will be equal to BC. (From Schmidt, A. C.: Verhandl deutsch. orthop Gesellsch 41 Kongress pp 195-220, 1954 Ferdinand Enk Verlag Stuttgart.)

The actual fusion area in poliomyelitis is t from parallel to parallel vertebrae the ma fusion area. In some idiopathic curves, fusion minimum is adequate, in others it may be nec to include the entire maximum fusion area actual fusion area is, therefore, dependent on factors, such as etiology age of patient, and ibility of the primary and secondary curv general, when there is a high percentage of tural changes in the mixed curves in a youn tient, it is wise to fuse well into the mixed or to include the maximum fusion area

Unbalanced Curve. When the actual fusion is less than the maximum, an obliquely placed column should be avoided.

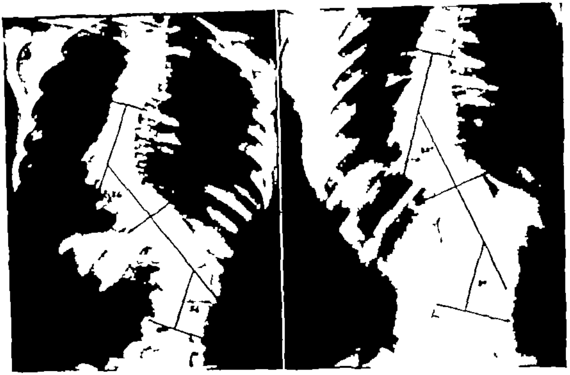
In a curve which is not a true arc, as sho Fig 154 vertebrae *A* and *C* are the two end brae, as determined by former analysis. Fus this curve would result in an unbalanced co certainly not conducive to compensation. A distal vertebrae, *A* should be chosen in ord balance the curve. This rule will be satisfied the perpendicular intersecting lines, *AB* and used *for measuring the curve to be fused, app* equal length.

It is an accepted fact that a continuous co is more efficiently controlled than a segmented It is also obvious that the fusion of a segm scoliotic curve corrected into a straight or n straight continuous column, increases the ease which it can be controlled.

Multiple Primary Curves. In the roentgenogr Fig 155 *A* taken before fusion, and Fig 15 after fusion of both curves, the following are de strated.

The curves D6 to D11 and D12 to L3 had same characteristics with regard to angular ation on both standing and lateral bending were therefore classified as double primary cu The terms "double" or "multiple" pertainin primary curves, indicate that these curves have ilar characteristics upon analysis. It does not ne sarily indicate the same time of origin. At the of the growth period fusing only the upper curve double primary curve may be sufficient. If the tient has not quite reached the end of his gro period the actual fusion area should appr parallel ends or the maximum fusion area. In yo *patients, fusion of both curves is indicated.*

Forced Rotation. When a primary curve exte low on the lumbar spine the lower vertebra vertebrae of that curve are usually compelled



A. B.

Fig 155. A, This roentgenogram shows a double primary curve with patient in the standing position before fusion. Rotation of L4 would place it within the lower primary curve; however, the shortness of the lower fractional curve, situated between a curve of great magnitude above and the sacrum below, has forced L4 to rotate beyond the neutral. L3 reveals maximum tilting. The intervertebral space above L3 is wider on the convex side of the curve, and the intervertebral space below L3 reveals no wedging, both indicating that L3 is in this case the terminal of the lower primary curve rather than L4, which has been forced to rotate. B, Roentgenogram showing the double primary curve corrected and fused. (From Schmidt, A. C., Verhandl. deutsch. orthop. Gesellsch. 41 Kongress, pp 193-220 1934 Ferdinand Enk Verlag Stuttgart.)

rotate beyond the neutral (Fig 155 *A*). L3 is the vertebra which is most tilted. The intervertebral space above it is wider on the convex side of the curve, whereas the space below shows no wedging. The short fractional curve, L4 to sacrum, inclusive, caused by the magnitude of the curve above it, has forced not only L3 but also L4 to rotate beyond the neutral. However, two of the three elements which determine the end of a curve are evident at the level of L3; therefore, in this case L3 is the lower end vertebra.

Errors in Fusion. Fusion of the wrong curve in a growing child is often disastrous. When the primary curve or curves are too greatly overcorrected, and the lower compensatory curve is more rigid than the upper, a pelvic tilt will be in evidence. When the upper is more rigid than the lower, the shoulders will be tilted. In a growing child, it is better to err on the side of overcorrection than undercorrection. In a patient who has attained or nearly attained his maximum growth, overcorrection may result in the patient being permanently off balance. Inadequate length of fusion allows deformity to recur, especially with considerable growth.

In regard to conservative treatment of scoliosis, Cobb[4] says, "Exercises do not prevent increases in the curve if it is increasing; seldom, if ever, they appreciably decrease the curve permanently. Exercises improve the muscle tone, vital capacity, appearance, posture, and health, but do not alter the course of the progress of the curve. However, a scoliotic patient having a marked postural defect can reduce lordosis and kyphosis by elongating the spine through postural exercises, thereby indirectly decreasing the lateral curve."*

From Cobb, J. R., Outline for the Study of Scoliosis, American Academy of Orthopaedic Surgeons, Instructional Course Lectures, Ann Arbor 1948 J. W. Edwards, vol. 5, pp. 261-275

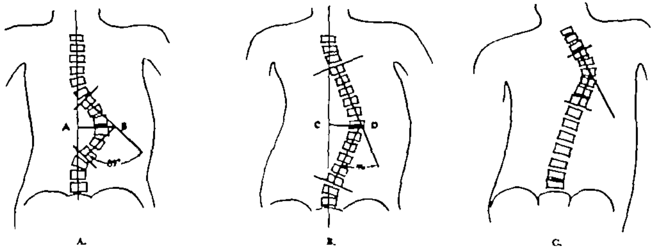


Fig. 156. Diagrams showing different locations of curves in the spine and indicating the resultant cosmetic deformities. (From Schmidt, A. C.: Verhandl. deutsch. orthop. Gesellsch. 41 Kongress, pp. 195-220, 1954. Ferdinand Enke Verlag, Stuttgart.)

Deformity Produced by Location and Length of Curves. The deformity produced by a curve is dependent upon the degree of the curve, the length of the curve, and probably most important of all, the location of the curve in the spine. Fig. 156 *A* represents an acute curve with a marked angulation producing very little cosmetic deformity due to the fact that it is an acute curve located in the dorsolumbar region. In Fig. 156 *B* you will note an extremely long curve with considerably less angulation, resulting in a marked deformity of the torso, due to the length of the curve. Fig. 156 *C* shows a relatively minor curve, but because of its location and the fact that it extends just beyond the shoulder level, it has produced a marked tilting of the shoulders.

THE MANAGEMENT OF PARALYTIC SCOLIOSIS

In our series, the most common type of scoliosis is idiopathic. The second most common type of scoliosis is due to poliomyelitis. The most common time for a scoliosis to increase is during the rapid growth period, and that of poliomyelitis origin frequently becomes severe soon after the onset of the disease, when the patient becomes ambulatory. Fusion should be postponed until as near to the ideal fusion age as possible, but a rapidly increasing curve at an early age may require correction and fusion. The actual fusion column should have parallel or nearly parallel ends. This is particularly true in the younger patient, and since the secondary curves are more flexible, overcorrection can be tolerated.

Moe states that high cervicothoracic paralytic curves should have immediate correction and fusion. Any delay usually results in irreversible changes, producing severe cosmetic deformity.

Blount and associates[4] observed: "Fusion of the spine in a growing child will somewhat restrict longitudinal growth. It is better, however, to have a moderately short straight torso than a very short crooked one. The mechanical lengthening of the spine obtained by correcting the curve usually exceeds the future restriction of longitudinal growth.

"Significant progressive thoracic lordosis has not been observed following spine fusion. A flat or lordotic thoracic spine is frequently found in scoliotic patients with rotation of the vertebrae particularly after partial correction of the curve by side bending. *This flat back often rounds out again after* operation and the use of the Milwaukee brace."*

The Role of the Abdominal and Sacrospinalis Muscles in Paralytic Scoliosis. The torso, with its semirigid rib cage, is joined to the pelvis by the movable lumbar spine, a universal joint, and held erect over the pelvis by the abdominal and the sacrospinalis muscles; these can be compared to guy wires. The abdominal muscles consist of the rectus abdominus, abdominal oblique, abdominal transverse, and the quadratus lumborum, all of which are paired. When one or more of the guy wires break or loosen up, the flexible column it is supporting begins to sag or bend. A paralysis or partial paralysis of one or more of the abdominal muscles usually results in a scoliosis. The efficiency of the

* From Blount, W. P., and co-workers: The Milwaukee Brace in the Operative Treatment of Scoliosis. J. Bone & Joint Surg. 40-A: 511, 1958.

guy wires in holding the column erect is in direct proportion to their distances from the column. Scoliosis is, therefore, usually more frequent and more severe following a paralysis of the abdominal muscle group than the sacrospinalis group due to the latter's close proximity to the spinal column.

Abdominal Fascial Transplants. Improved gait and stability are obtained by connecting the ribs to the pelvis with Lowman's fascial transplantations * in a patient with complete or nearly complete abdominal paralysis. It enables the individual to lift the anterior aspect of the pelvis mainly by elevating the rib cage instead of elevating it by markedly hyperextending the spine with each step. In a unilateral paralysis of the abdominal muscles the pelvis drops on the weak side, producing a lumbar curvature with convexity to the weak side. A lateral fascial transplant from the pelvis to the ribs on the paralytic side is desirable in stabilizing the pelvis. Abdominal fascial transplants, if inserted properly decrease the deforming forces causing scoliosis. They also stabilize the spine and improve the gait but will not alter the course or progress of a structural curve if it is developing.

The Role of the Iliotibial Band in the Causation of Scoliosis. A unilateral contracture of an iliotibial band usually produces a pelvic obliquity tilting the pelvis downward on the contracted side. More often than not, it is accompanied with a hip flexion deformity also. When the abducted and flexed hip is brought down into the position of standing, the pelvis is not only tilted downward on the contracted side but it is also tilted forward producing a swayback deformity. Before treatment is begun, it is imperative to determine the amount of structural changes that exist both above and below the pelvic brim. A roentgenogram of the spine on a large plate, taken with the patient in the sitting position, including at least the first sacral segment, will reveal whether or not the spine will straighten completely. Any correctable pathological condition below the pelvis contributing to the causation of the scoliosis should be corrected prior to the treatment of the scoliosis. If the contractures below the pelvic brim are released early, secondary changes are not likely to occur above the pelvis, but if they are allowed to persist over a long period of years, the spine above the pelvic brim will take on structural changes.

The patient next discussed was first seen at the age of 2 years two months after the onset of poliomyelitis (Figs. 157 to 161). He had at that time and still has completely flail legs. The lower abdominal muscles were completely paralyzed, and there was only a trace of power noted in the upper. Because of an abduction contracture of the left hip the iliotibial band was released surgically on that side seven months following the onset of the disease. The pelvis on the left continued to drop. This was assumed to be due mainly to the complete paralysis of the lateral abdominals on the left. The left side of the pelvis was anchored two months later to the ninth rib with fascia lata. To enhance the function of the upper abdominal muscles, since the lower were completely paralyzed, a second subcutaneous fascial band was anchored to the iliac crest on one side, crossing the midline above the umbilicus and then attaching to the opposite iliac crest. Following these transplantations the pelvis again dropped slightly but, in spite of that considerable stability was obtained. Due to the anchorage of the upper abdominals to the fascial transplant, these muscles again were able to perform a useful function.

Fig. 157, a roentgenogram taken of the patient at the age of 6 years, in the sitting position, shows two

Fig. 157 Roentgenogram of a 6-year-old boy illustrating a common type of deformity following a paralysis of the abdominal muscles. See also Figs. 158 to 161

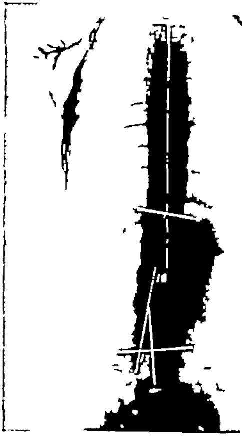


Fig 158. Roentgenogram seven and one-half months following correction and fusion of D3 to L4 inclusive, patient in standing position, at the age of 7 years

Fig 159 Roentgenogram one and one half years following fusion A marked tilt of the pelvis has developed

curves of approximately equal magnitude and in addition, a marked decompensation. This pattern is frequently found in scoliosis of poliomyelitis origin when there is a marked paralysis of the abdominal muscles. It has been our experience with scoliosis, such as the case described that fusion of practically the entire dorsal spine down to and including the third or fourth lumbar vertebra is necessary to obtain compensation. In this case it is obvious that L4 had to be included.

Fig 158 a film made seven and one half months following correction and fusion from D3 to L4 inclusive at the age of 7 years, shows the patient standing with the aid of crutches. As you can see, the pelvis had practically assumed the horizontal position. The spine is now well compensated when he is walking with the aid of crutches. By correcting and fusing a long column in a decompensated scoliosis, the weakened torso muscles can again function more efficiently producing compensation

Fig 159 a roentgenogram taken one and one half years after fusion, shows that an exaggerated tilting of the pelvis has again developed Levelling off the pelvis and fusing down to the sacrum would be a solution However overcorrection or undercorrection would throw the patient permanently off balance I have also observed free and painful motion develop at the sacroiliac joints, following fusion of the entire spine when the sacrum has been included. In this particular case, I chose to level off the pelvis as much as possible by using Hoke well leg traction. It was maintained in that position by reefing the original ninth rib fascial transplant and inserting two additional ones, one to the seventh and another to the eighth rib respectively

Fig 160 shows the patient standing nine months after the addition of the second fascial transplant.

Fig 161 is a roentgenogram of the patient in the standing position at the age of 9¼ years, taken two years following the second fascial transplantation and it indicates that there has been no increase in the pelvic tilt within the last year This method delayed and may possibly have eliminated the need for further fusion of the remaining flexible spine Maybe further reefing of the fascial strap or even stapling the right lower femoral epiphysis will solve the problem. I still hope to bring about a compensated

Fig. 160. Pelvic tilt has been markedly reduced with well-leg traction. This roentgenogram was taken nine months after addition of the second fascial transplant.

Fig. 161. Final roentgenogram taken one year later showing that there has been no increase in the tilt of the pelvis.

Fig. 162. Two years after onset of poliomyelitis without definitive treatment. See also Figs. 163 and 164.

Fig. 163. Two and one-half years following correction and fusion.

spine without fusing down to the sacrum.

Fig 162 shows a 15-year-old girl who had poliomyelitis at the age of 10 years. Her deformity was allowed to progress even though the parents tried to seek good medical advice. This long, fixed curve exhibits an extreme degree of deformity The primary curve from D6 to L2 measures 97 degrees. It could be corrected only to 81 degrees on her original visit, indicating that it was extremely rigid.

In Fig 163 two and one-half years after fusion from D4 to L3 the curve measures 43 degrees. As you will notice the shoulders are practically horizontal and are centered over the pelvis. In spite of the long and rigid curve, adequate correction was obtained.

As you can see from the photographs in Fig 164 the patient is well compensated, and cosmetically it is a satisfactory result

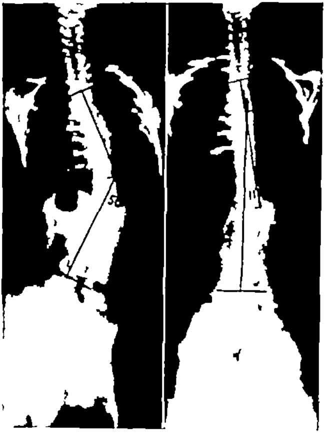
Fig 165 *A* shows a 13-year-old boy demonstrating a scoliotic curve of poliomyelitis origin the patient had a 50 degree curve which extended from D4 to L4 In *B* five years after fusion, the curve measures 11 degrees.

Fig 166 *A* is identified as a "roentgenogram of a woman, 29 years old, while standing Poliomyelitis at the age of 2 years left the patient with a left thoracic, kyphoscoliosis curve of 187 degrees with 80 degrees of rotation. She had had no support except a corset. The respiratory embarrassment was so great that she could not walk more than a block or two and she could not stand or sit for more than two hours without excessive fatigue and back pain. Employment was impossible. Two years after partial correction with the Milwaukee brace, rib resection on the side of the concavity and four stage fusion on the side of the concavity with autogenous iliac and rib grafts from the first thoracic vertebra to the sacrum [Fig 166, *B*] Subsequent exploration showed that the graft was solid. A four inch gain in height required the use of skull tongs to permit removal and remaking of the brace between stages. The patient's respiratory function was greatly improved and she was able to work steadily"[*]

[*] From Blount, W P and co-workers: The Milwaukee Brace in the Operative Treatment of Scoliosis, J Bone & Joint Surg 40-A: 511 1958.

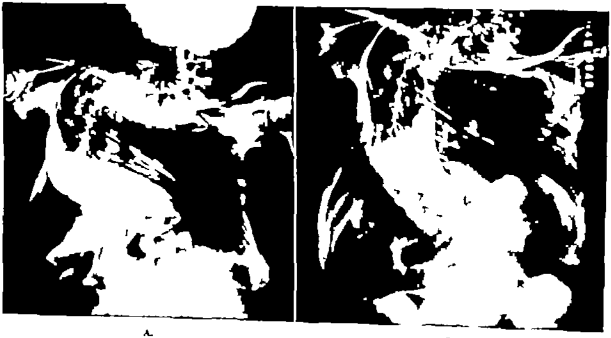
A B C

Fig. 164 A, Photograph before correction and fusion. B Photograph after correction and fusion C, Patient in street clothes



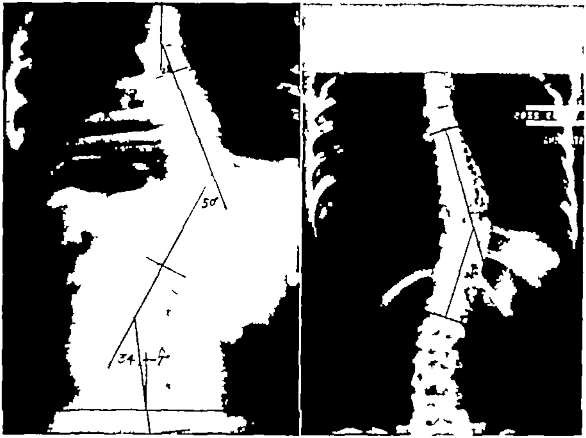
A. B.

Fig 165. A, Roentgenogram of scoliosis due to poliomyelitis. Note the long curve resulting in marked cosmetic deformity B, Roentgenogram of the patient five years after fusion. (From Schmidt, A. C. Verhandl. deutsch. orthop. Gesellsch., 41 Kongress, pp. 195-220 1954 Ferdinand Enke Verlag Stuttgart.)



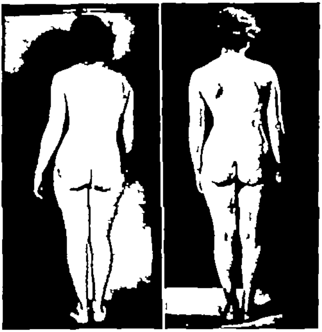
A. B.

Fig. 166. A, Roentgenogram of a 29-year-old woman, exhibiting an extreme degree of deformity prior to fusion (patient of Dr Blount) B, One year after fusion. (From Schmidt, A. C.: Verhandl. deutsch. orthop Gesellsch., 41 Kongress, pp. 195-220 1954 Ferdinand Enke Verlag Stuttgart.)



A. B.

Fig. 167 A, Roentgenogram of an idiopathic scoliosis before fusion. B, Roentgenogram of the same patient six years after fusion. (From Schmidt, A. C. Verhandl deutsch. orthop. Gesellsch 41 Kongress, pp. 195-220 1934 Ferdinand Enke Verlag Stuttgart.)



A B

Fig 168. A, Photograph of patient shown in Fig. 167 before fusion. B, Photograph six years later (From Schmidt, A. C.: Verhandl. deutsch. orthop. Gesellsch., 41 Kongress, pp. 195-220 1934 Ferdinand Enk Verlag Stuttgart.)

TYPES OF SCOLIOSIS

Idiopathic Scoliosis. Idiopathic is the most common type of scoliosis. It is more frequent in girls than boys, but does not progress beyond the growth period, which in girls ends at 14 and in boys, at 17 years of age. The curvature increases more rapidly during the rapid growth period, which is between the ages of 11 and 15 years. Immaturity of the patient and failure to obtain adequate correction frequently demand that the area of fusion include one or two vertebrae above and below the minimum fusion area. Each case is an individual problem, but the decision to correct and fuse is made when there is rapid progression of a moderate curve or the existing curve is not acceptable.

Fig 167 *A* shows an idiopathic scoliosis. The patient was 14 at the time of fusion. The primary curve measured 50 degrees before correction. Fig 167 *B* taken six years after fusion, shows that the curve is 33 degrees. Photographs show the patient before fusion and six years later (Fig 168)

The primary curve in this 12 year-old boy also an idiopathic scoliotic, measures 85 degrees (Fig 169 *A*) One year after fusion, it measures 40 degrees (Fig 169 *B*)

This 16 year-old girl (Fig 170 *A*) also an idiopathic scoliotic prior to fusion had a primary curve of 43 degrees. A year later a pseudoarthrosis was discovered, and she was re fused. Three years following the last fusion the curve measured 18 degrees (Fig 170 *B*) Photographs show the patient before fusion and four years later (Fig 171)

Congenital Scoliosis. The congenital type of scoliotic curve frequently increases rapidly at an early age. I have not hesitated to fuse this type of increasing curve even though the patient was only 4 years of age. It is preferable to extend the fusion area several vertebrae beyond the primary curve on both sides of the curve.

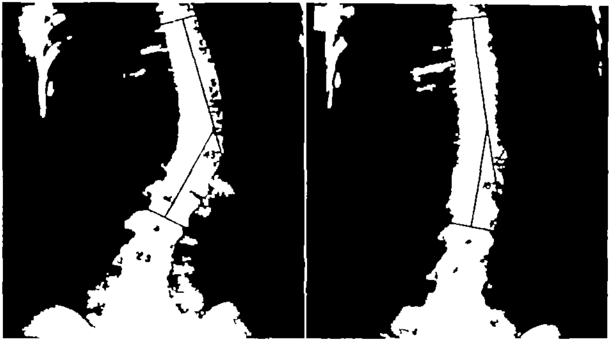
Fig 172, *A* is a roentgenogram of a 4 year-old congenital scoliotic showing a marked tilting of the pelvis and shoulders

Fig 172, *B* a roentgenogram two years following fusion, reveals the shoulders to be level, but a slight list to the right is still present. Note the decrease in angulation of the congenital continuous bar on the concave side of the scoliotic curve. Correction was obtained by a Milwaukee brace.

In Fig 173 four years following fusion, the tilt of the shoulders has become quite marked. It was assumed that the deformity had recurred due to the additional hemivertebrae on the convex side of the

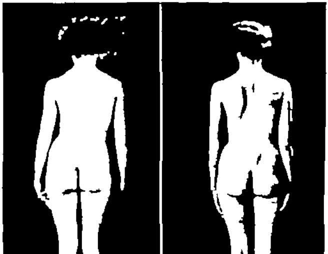
A. B.

Fig 169 A, Roentgenogram of an idiopathic scoliosis before fusion. B, Roentgenogram one year after fusion. (From Schmidt, A. C. Verhandl. deutsch. orthop. Gesellsch 41 Kongress pp. 195-220 1954 Ferdinand Enk Verlag Stuttgart.)



A. B.

Fig 170. A, Roentgenogram prior to the first fusion, revealing marked list in a patient with idiopathic scoliosis. The first fusion resulted in pseudoarthrosis. B, Roentgenogram taken three years following the last fusion. (From Schmidt, A. C.: Verhandl. deutsch. orthop. Gesellsch., 41 Kongress, pp. 195-220 1954 Ferdinand Enke Verlag Stuttgart.)



A B.

Fig 171 A, Photograph of the patient shown in Fig. 170 before fusion. B, Photograph three years following the last fusion. (From Schmidt, A. C. Verhandl. deutsch. orthop. Gesellsch., 41 Kongress pp. 195-220 1954 Ferdinand Enke Verlag Stuttgart.)

A. B.

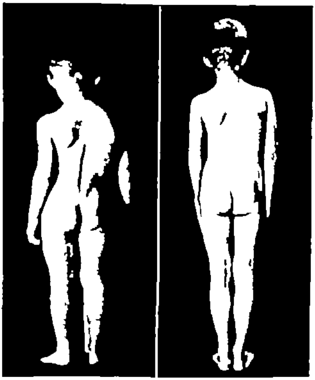
Fig. 172. A, Roentgenogram of a 4-year-old congenital scoliotic. B, Two years following fusion. See also Figs. 173 and 174. (From Schmidt A. C. Verhandl. deutsch. orthop. Gesellsch., 41 Kongress, pp. 195-220 1934 Ferdinand Enke Verlag Stuttgart.)

Fig. 173 Recurrent deformity four years following fusion

Fig. 174 One year following spinal osteotomy

A. B.

Fig. 175. A, Roentgenogram of a patient, 6 years of age, with a scoliosis due to neurofibromatosis before fusion. This patient was re-fused one year later due to pseudoarthrosis. B, Four years following the last fusion. (From Schmidt, A. C. Verhandl. deutsch. orthop. Gesellsch. 41 Kongress, pp. 195-220 1954 Ferdinand Enke Verlag Stuttgart.)



A. B.

Fig. 176. A, Photograph of the patient in Fig 175 before original fusion. B, Four years after the last fusion. (From Schmidt, A. C.: Verhandl. deutsch. orthop. Gesellsch., 41 Kongress, pp. 195-20 1954 Ferdinand Enke Verlag Stuttgart.)

A. B.

Fig. 177 A, This boy at the age of 5 years had a scoliosis, associated with arachnodactyly showing unusual curves. B, Roentgenogram two years after the fusion of both curves. (From Schmidt, A. C. Verhandl. deutsch. orthop. Gesellsch., 41 Kongress, pp. 195-220 1954 Ferdinand Enke Verlag Stuttgart.)

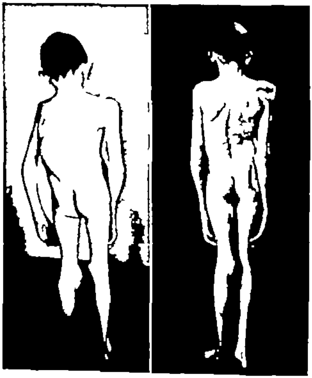


Fig. 178. A, Photograph of the patient shown in Fig. 177 before fusion. B, Two years after fusion. (From Schmidt, A. C. Verhandl. deutsch. orthop. Gesellsch., 41 Kongress, pp. 195-220 1954 Ferdinand Enke Verlag Stuttgart.)

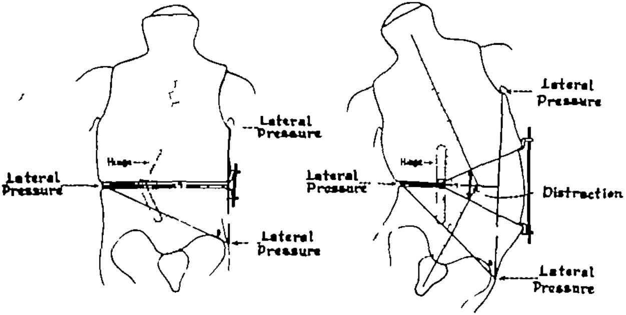


Fig. 182. These diagrams illustrate that by placing a hinge eccentrically in a turnbuckl jacket, distraction or oblique traction is always incorporated. (From Schmidt, A. C. Verhandl. deutsch. orthop Gesellsch 41 Kongress, pp. 195-220 1954 Ferdinand Enke Verlag Stuttgart.)

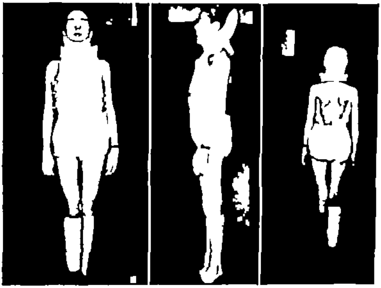


Fig 183 Three views of distraction plaster jacket.

are incorporated in most forms of correction *whereas the additional force of derotation is utilized* in only a limited number of methods. Figs. 179 180 and 181 graphically evaluate the efficiency of the forces of lateral pressure and distraction in correcting a scoliosis Forces of both lateral pressure and distraction are utilized when correcting a curve by *means of a turnbuckle cast if the hinge is eccentrically* placed as shown in Fig 182

We can then postulate the following

1 The efficiency of distraction is in direct pro*portion to the degree of curvature.*

2 The efficiency of lateral pressure depends on the ratio of the width to the length of the torso.

3 A wedged cast molded about the chin and pelvis corrects the curve by means of both distraction and lateral pressure.

4 The Milwaukee brace incorporates all three forces lateral pressure distraction, and derotation.

Fig 183 consists of photographs showing a dis-

Fig. 184 Fig. 185. Fig. 186.

Figs. 184, 185, and 186. Various views of the Milwaukee brace.

traction plaster jacket in which are incorporated greased metal vertical bars, allowing only distraction.

Figs. 184, 185 and 186 are various views of the Milwaukee brace which was developed by Dr Blount and myself.

The orthopaedist who is not too familiar with the treatment of surgical scoliosis should start with simple cases and, as he gains confidence undertake the more complicated ones. It requires actual experience to understand the surgical treatment of scoliosis. If the rules set down are followed, good results can be expected.

The major factors contributing to my own failures have been a combination of or any one of the following:

1. Insufficient correction of the curve or curves to be fused.
2. Inadequate length of fusion.
3. Pseudarthrosis (probably the most important of all).

SUMMARY

The aim of the surgical treatment of scoliosis is to achieve the following goals.

1. Straighten the primary curve or curves to their maximum, and retain or improve compensation.
2. Maintain correction of the curve or curves by fusion.

The approach to this problem is to

1. Identify the primary curve or curves by analysis of standing roentgenograms.
2. Estimate the amount of correction desirable or obtainable by lateral bending tests to determine the amount of structural changes.
3. Correct the curve using either lateral pressure, distraction, derotation or preferably all three.
4. Select the proper segment to be fused.
5. Fuse the selected area (a) arthrodese the facets (b) sliver the exposed cortical bone (c) add autogenous bone as indicated.

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END RESULTS OF REMOVAL OF PROTRUDED LUMBAR INTERVERTEBRAL DISCS WITH AND WITHOUT FUSION

Any operation on the skeletal system must stand the test of time before it can be judged either a success or a failure. Operations for removal of protruded intervertebral discs are no exception.

Soon after the recognition of the protruded inter vertebral disc as an entity to explain low back and sciatic pain there were glowing reports of the success of the removal of the protruded fragments of the disc. Reports of 90 to 95 per cent relief of symptoms were not uncommon and the operation gained favor not only among the medical profession but among lay persons as well. Scoffers and doubting Thomases gradually climbed aboard the band wagon. Some who questioned at first whether there were such lesions finally became so convinced of their presence that they attributed low back and sciatic pain to protruded discs in all cases. Some even advocated immediate operation without the use of supportive tests to confirm the diagnosis. By now the fallacy of this concept is well established and all physicians recognize that an accurate diagnosis must be made before treatment is instituted, in order to avoid missing other lesions which cause symptoms that may simulate those of the protruded disc.

When an accurate diagnosis has been made, the treatment of the protruded disc must relieve the patient of sciatic pain, as well as backache. To re lieve a patient of sciatica only to leave him with a disabling backache or to relieve the backache and not the sciatic pain is not a good result. Both the backache and sciatic pain must be relieved (long period if the operation is to be call success."

Early reports of the results of removal o truded discs considered only the relief of sciati and that for only a short period. Many of u dered what the long range result would be anc would happen to the backache of the patien an associated lesion of the spinal column. brings up the problem of whether or not to fu vertebrae following removal of the protruded p of a disc. Up to now the problem remains un Only time and careful surveys of end resul answer the question.

OUR INDICATIONS FOR FUSION

At the Mayo Clinic we began in 1938 to identify before operation the patient who b of spinal abnormalities, might have persistent ache after removal of a protruded disc, an would be better treated by simultaneous The first indication for fusion was the p of spondylolisthesis. To this was gradually spondylolysis, localized degenerative arthritis, sacralization, scoliosis, vertebral fractures, de ative changes of the facets, the finding of six l vertebrae and some other congenital anomal turn, fusion was performed in other cases in the only finding was a narrowed lumbosacra or in which the joint was judged unstable

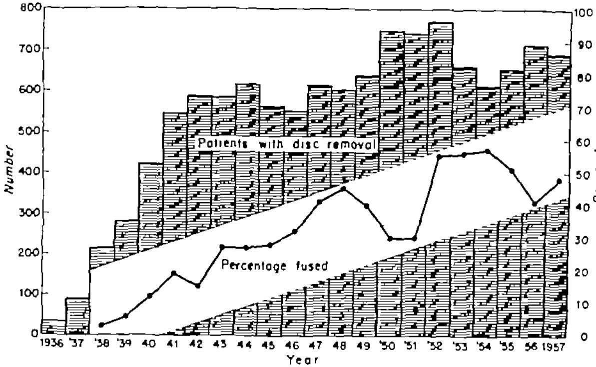

Fig 187 Operations for protruded intervertebral disc at the Mayo Clinic from 1936 through 1957

time of operation even though the roentgenograms revealed no skeletal change. These patients gave a history of backache of long standing that was static in type, that is, aggravated by activity and relieved by rest. Fusion operations were performed on a number of our patients who were found to have recurrent protrusion of the disc in spite of normal roentgenograms of the spinal column.

Special mention probably should be made of that group of patients who have symptoms of protruded disc and a static type of backache and who present *narrowing of the intervertebral space as the only* roentgenographic finding The greatest increase in number of combined operations at the Mayo Clinic has taken place in this group of patients. In the three years prior to 1941 only thirty-eight patients underwent the combined procedure because of narrowed *interspaces The annual number gradually in*creased until, in 1944 alone, it reached fifty-eight.

The Narrowed Interspace. Whether or not the finding of a roentgenographically narrowed interspace constitutes an indication for fusion is debatable It seems only reasonable to assume that if *sufficient cartilage extrudes from between two verte*brae, the interspace may narrow further Likewise if the protrusion is due to a degenerative process in the disc, one may assume that this process is going to continue and will lead to further narrowing With further narrowing osteoarthritic changes occur and the joint becomes a source of pain and disability to the patient. We have observed these changes in the unfused spinal columns of some patients after removal of protruded discs and believe that this is the reason for the increase in the number of fusions performed in this group of patients. The fusion is done not only to help relieve the present symptoms but also to help ensure a long-term good result without a secondary operation. The gen*eral trend at the clinic has been a gradual increase* upward in the percentage of patients treated by fusion following removal of the disc (Fig 187)

The gradual increase in percentage has been due to an actual increase in the number of operations for recurrent protruded disc and to the development *of the concept that patients having a narrowed in*terspace as the roentgenographic finding are more likely to have a long term good result if fusion is performed after the protruded part of the disc is removed The justification for continuance of this procedure can be based only on the long term re*sults in this group as compared with the results in a* similar group of patients who have undergone removal of a protruded disc without simultaneous bone grafting

MATERIAL STUDIED AND METHODS

In order to judge the results of removal of the protruded portion of the disc alone versus its removal and fusion two groups of patients were traced for a minimum of six and a maximum of ten years after the operation. We were able to trace 450 patients who had had the combined operation and 555 who had only had the protruded disc removed

Relief of sciatica, as well as the relief of backache, was studied in both groups. The result was graded as good for each type of pain if complete relief was reported fair if the symptom was partially relieved and poor if the pain was the same as before operation, or worse. Thus an excellent result was one in which the patient reported complete relief of both sciatic pain and backache at the other extreme was total *failure that is, the patient's* backache and sciatic pain were the same as or worse than before operation. Between these two extremes were several different groups partially relieved of one or the other symptom.

For the sake of those who advocate only the removal of the protrusion and no fusion in spite of skeletal changes, it should be pointed out that the skeletal changes as observed roentgenographically in the two groups were similar except that there were no cases of spondylolisthesis or arthritis of the facets *in the group treated by removal of disc alone*. Otherwise the groups were comparable. Likewise, advocates of no fusion might state that the inclusion of spinal abnormalities lowered the good results in their series of cases This did not prove to be true in our study for if these cases were eliminated the result for the group remained unchanged.

RESULTS

The over-all end results of the two operations in this series are given in Table 5 Whereas the combined operation completely relieved the backache of 68 per cent of the 450 traced patients and the sciatic pain of /4 per cent, removal of the protruded disc alone completely relieved the backache of only 48 per cent and the sciatic pain of 53 per cent of the 555 patients so treated. There was a poor result for each type of pain in 5 per cent in the combined operation group and a poor result for backache in 16 per cent and for sciatic pain in 15 per cent in those treated by removal of the protruded disc alone The other patients in both groups received partial relief of both symptoms and were judged as having fair results. The significant finding in this analysis is that the combined operation relieved both symptoms in 20 per cent more *patients than the operation for* removal of the protruded disc alone and that there were three times as many failures to obtain relief of each type of pain when the fusion was not performed. Simultaneous fusion appeared to have had an "acceptable" result, that is some relief was obtained in 95 per cent of the patients, as compared to 85 per cent in the unfused group

We next compared the relief of sciatic pain with relief of backache in the same patient. The degree of relief of sciatic pain in the 68 per cent of the patients who received complete relief of their backache by the combined operation and in the 48 per cent who received relief of backache by the operation for removal of the disc alone is reported in Table 6 In the combined operation group 63 per cent of the *patients were relieved of sciatic pain also*, whereas only 44 per cent were relieved of sciatic pain by removal of the protruded disc alone. Again this represents a 20 per cent better result when fusion accompanies removal of the protruded disc.

The "fair" results in both groups of cases are

Table 5 Percentile Summary of Results of the Combined Operation Versus Removal of Disc Only

	Symptom	Result (%)		
		Good	Fair	Poor
Combined operation (450 traced patients)	Backache	68	7	5
	Sciatic pain	74	21	5
Removal of disc without fusion (555 traced patients)	Backache	48	36	16
	Sciatic pain	53	32	15

Table 6 Degree of Relief of Sciatic Pain in Cases in Which Complete Relief of Backache Was Obtained

	Patients	Relief of Sciatic Pain		
		Good	Fair	Poor
Combined operation (304 patients 68% with complete relief of backache)	Total	283	19	2
	Percentage of 450 traced patients	63	4	<1
Disc removal only (266 patients, 48% with complete relief of backache)	Total	245	21	0
	Percentage of 555 traced patients	44	4	0

Per cent of patients undergoing the operation.

Table 7 Degree of Relief of Sciatic Pain in Cases in Which Partial Relief of Backache Was Obtained

	Patients	*Relief of Sciatic Pain*		
		Good	*Fair*	*Poor*
Combined operation (123 patients, 27%* with partial relief of backache)	Total	47	73	3
	Percentage of 450 traced patients	10	16	<1
Disc removal alone (20? patients, 36%* with partial relief of backache)	Total†	42	145	14
	Percentage of 555 traced patients	8	26	3

* Per cent of patients undergoing the operation.
†One patient had no sciatic pain before operation

Table 8 Degree of Relief of Sciatic Pain in Which Backache Was Not Relieved

	Patients	*Relief of Sciatic Pain*		
		Good	*Fair*	*Poor*
Combined operation (23 patients, 5%* whose backache was not relieved)	Total†	1	4	17
	Percentage of 450 traced patients	<1	1	4
Disc removal only (87 patients, 16%* whose backache was not relieved)	Total	4	11	72
	Percentage of 555 traced patients	<1	2	13

* Per cent of patients undergoing the operation.
†One other patient had no sciatic pain before operation.

given in Table 7 No particular comment can be made concerning them except to say that they were *somewhat better in the combined operation group* than in the group having the disc removed alone.

The percentage of cases in which neither operation relieved the backache and the over-all failure in relief of sciatic pain are indicated in Table 8. Of the twenty three patients (5 per cent) who were treated by the combined operation and who failed to gain relief of their backache, seventeen (4 per cent of the entire group) also failed to gain any relief of sciatic pain. This indicates an over-all total failure of 4 per cent in the combined operation group Of *the eighty-seven patients (16 per cent of the whole* group treated by removal of the disc alone) who failed to gain relief of backache seventy-two (13 per cent of the whole group) failed to gain any relief of sciatic pain, an over all total failure of 13 per cent.

COMMENT

The preceding statistics indicate that the chances for a long term good result are approximately 20 per cent better after the combined operation than after removal of the protruded portion of the disc without fusion, and the chances of total failure are about three times higher when the fusion is omitted. Why should this discrepancy in figures be present in a long term follow-up series when the immediately postoperative results seem to be fairly comparable in *the two groups? We believe that this question may* be answered as follows.

A spinal column which is fused remains solid and even gets stronger as time goes by and the graft hypertrophies with the stress and strain on it. On the other hand, if a disc protrudes only because of a degenerative process present in it the simple removal of the protruded fragments does not stop progression of the degeneration. As degeneration continues, a back that has been symptomless may begin to pain and may inconvenience the patient so much *that he will seek further medical aid*

By now every orthopaedic surgeon must realize that multiple operations on the spinal column are fraught with failure and that the optimal time to perform a fusion is at the first operation, if it is to be necessary ultimately At present we do not believe that all spinal columns should be fused after removal of the protruded portion of a disc even though the statistical evidence seems to point to this conclusion. Each patient should be evaluated individually and if his age occupation, history physical condition, or roentgenograms indicate the procedure to be in his favor he should have a fusion after removal of his protruded intervertebral disc.

PART SIX

UNEQUAL EXTREMITIES, OSTEOMYELITIS, ELECTROMYOGRAPHY IN ORTHOPAEDIC SURGERY

CHARLES WEER GOFF M D
Hartford Connecticut

SURGICAL CARE OF UNEQUAL EXTREMITIES

Measuring and Predicting Growth

You can sail by dead reckoning if you are lucky and have many years experience plus a sixth sense of direction but the knowledge of a few principles of navigation is more likely to get you to port And so it is with growth expectancy Only the very skillful should "play it by ear" While a few surgeons may rely on that policy we should not do so.

In the first place it is unnecessary Many resources are available to the surgeon who must plan the care of children and adults with unequal extremities. His responsibility today is greater than ever With the former knowledge of growth in all its ranges becomes imperative And so it is that this course, designed to assist in making sound decisions, suggests the means and shows the ways of appraising growth of extremities that are unequal for one reason or another

MAN'S ASYMMETRY AND GROWTH ADAPTIVITY

Man is usually thought of as a symmetrically constructed individual. He is assumed to have arms and legs that match each other right with left. But such is rarely the case. A modicum of asymmetry is usually present, which can be detected if extremities are accurately measured although it may pass without notice, does not disrupt man's health or happiness, and is of only academic interest. For example, Rush and Steiner measured orthoroentgenographically one thousand random Army dischargees and gathered the following data. Lower extremities were equal in 23 per cent of the group and unequal in 77 per cent. When the right was shorter it was by a 0 747 cm. average the left was shorter by 0 65 cm., on the average

They found no correlation between unequal lower extremities and physical disorders other than a minimal postural scoliosis, asymptomatic in character

GROWTH OF THE CHIMPANZEE AND OF MAN

A close study of chimpanzees, which was made by myself and confirmed in a statistical analysis by Gavan showed a much greater proportional growth of the lower extremities in the human child. A prepubertal acceleration pushes the child's rate beyond that of the chimpanzee into the relative proportions of the adult extremities as shown in Table 9

Table 9 Adult Proportions of Extremities

	Chimpanzee	Man
Upper	4 6	3 7
Lower	2 9	4 0

This shows a selectivity operating in favor of man, among the primates for lower extremity specialization. This has given man greater speed on foot and a capacity for land travel while the chimp is a better climber over obstacles.

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Table 9 Adult Proportions of Extremities

	Chimpanzee	*Man*
Upper	4 6	3.7
Lower	2 9	4.0

This shows a selectivity operating in favor of man, among the primates, for lower extremity specialization. This has given man greater speed on foot and a capacity for land travel while the chimp is a better climber over obstacles.

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ture of a long bone into an epiphyseal zone or malunion are serious causes present on occasion. Great *loss of substance* as in *battle or automotive injuries* is increasingly observed.

There are undoubtedly many other causes, but the most frequent cause to date has been *poliomyelitis*. This may not exist for future generations of physicians, but most series of equalization procedures now are predominantly concerned with the child who has suffered such a paralysis. The shortening that follows depends upon the degree of muscle loss and the age at occurrence.

TEAM APPROACH

A growth team is essential for complete analysis of a child's status. This includes a pediatrician, an aide trained in physical anthropometry techniques and statistics, a physiatrist or aide, an endocrinologist when possible, and the orthopaedic surgeon. The last-named is in charge. Final decisions are his.

METHODS OF CALCULATING EXPECTED GROWTH INCREMENTS OF LOWER EXTREMITY

Wilson and Thompson[71] and later Straub, Thompson, and Wilson[1] described an ingenious method of calculating a child's expected extremity growth. Essentially they believe that a daughter will equal or excel the mother's growth and so will a son the father's growth. The parent's extremity length, usually measured clinically with a tape, is the base line or mean determination. This has a good deal of validity. Their results are good. For example, a boy at the chronological age of 12 years, with a discrepancy of 2 inches, or 5 cm., whose leg measures 30 inches, or 75 cm., has a father whose extremity measures 36 inches, or 90 cm. Their formula would apply as follows:

$$\frac{\text{Present discrepancy} = 2 \text{ inches}}{\text{Necessary growth (to equal father's)} = 6 \text{ inches}} = 33\%$$

This means that 33 per cent of the longer extremity's growth should be eliminated to achieve eventual equality. Now they have assigned 15 and 35 per cent and 30 and 20 per cent of the extremity's growth to the upper tibial and the lower femoral epiphyses, respectively. Their computations call for a total arrest of the lower femoral epiphysis of the longer leg in order to equalize the boy's extremities at their termination of growth. They *qualify their method* by noting that "it is not entirely accurate. Perhaps no method is. Sex and age of sexual maturation may also be important." They prefer the proportional growth percentages, which were computed by Digby from dry bones (see Table 10).

*Table 10. Digby's Growth Percentages for Whole Lower Extremity**

	Femur	Tibia
Proximal	15	30
Distal	35	20

*These make no allowance for sex, age, preadolescent or postadolescent rates of growth and do not correlate with stature in man.

However, these percentages have been verified as fair averages or means by other investigators. Hendryson reworked Digby's material and got a range for each epiphysis of 5 to 7.9 per cent with means about the same as Digby's. Digby measured from the center of each long bone shaft, where the nutri-

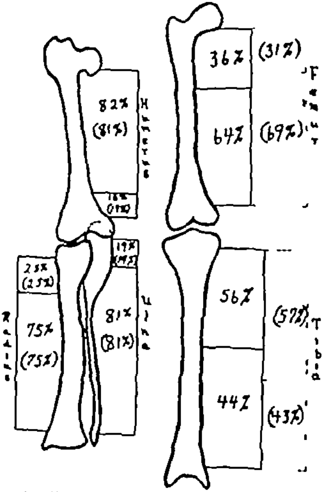

Fig. 169. Method of measuring and determining percentages of growth in the goat and in man. (From Bisgard, J. D., and Bisgard, M. E.: Arch. Surg. 31: 568, 1935.)

CONDITIONS WITH INEQUALITIES

Aside from the slight expected asymmetry found by Rush and Steiner inequality in leg length is particularly detrimental to man and his children since they are disposed to bipedalism. The causes are many but are classified rather easily If inequalities exist during the growing years, something can be done about the situation. After full growth has been attained the difficulties become greater

Soft Tissue Disorders. Contractures from any source at all are common causes, usually related to an underlying disorder such as a *partial paralysis of an extremity* or *severe burns* Sometimes the *trunk muscles* are *weak* on one side. A *tight tensor fascia femoris contracted lumbar fascia short gluteal muscles* and *tight hamstring and calf muscles* are frequent causes of a short leg *Pelvic obliquity* follows these and other shortening conditions—such as poliomyelitis, a dislocated hip spastic hemiplegic paralysis, or a clubfoot. *Combinations* are frequently found, including underlying skeletal disorders.

Developmental Disorders. These include a *congenitally dislocated hip* and the *hemiplegia* of the *cerebral palsied* as the common causes. Occasionally *congenital hyperplasia* appears, wherein one half of the body is larger and longer than the other half The condition is considered by some to be a phase of twinning—one half each of two fraternal twins. *Congenital shortening* of an extremity where the *growth rate is less* of one or more segments is not uncommon. Sometimes a *bone is absent* or may be *greatly angulated* False joints occur and *complete aplasia* may be found *Anomalies of blood vessels* such as an obstructive iliac vein, or a *neurofibromatosis* may cause a shortening or a lengthening of an extremity *Spina bifida* with deficiencies of nerve development, may lead to skeletal shortening of an arm or leg Occasionally a congenital coxa vara will be unilateral and a leg discrepancy will be present.

Acquired Disorders. The arthritides, bone cysts, bone tumors, and osteomyelitis cause growth inequality These may accelerate or decelerate growth, depending upon their nearness to a growth apparatus. *Volkmann's ischemic paralysis* and *Legg-Calvé-Perthes disease* decelerate growth, and shortening may follow *Disuse atrophy* when using the Snyder sling may contribute to the diminished growth. A *slipped upper femoral epiphysis* a *frac*

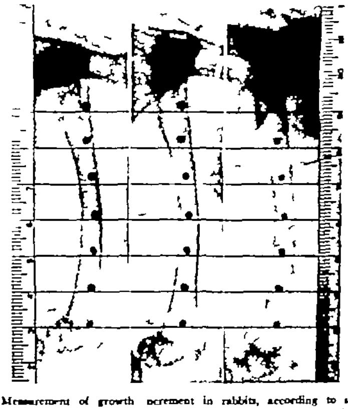

Fig. 188. Measurement of growth increment in rabbits, according to shot embedded along the side of shaft left, thirty day middle fifty-two day and right, eighty-four days. Note total absence of interstitial growth the rabbit. (From G tewood, and Mullen, B. P Arch. Surg 15: 215 1927)

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*Table 10 Digby's Growth Percentages for Whole Lower Extremity**

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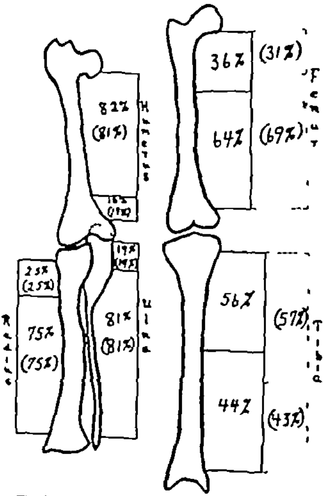
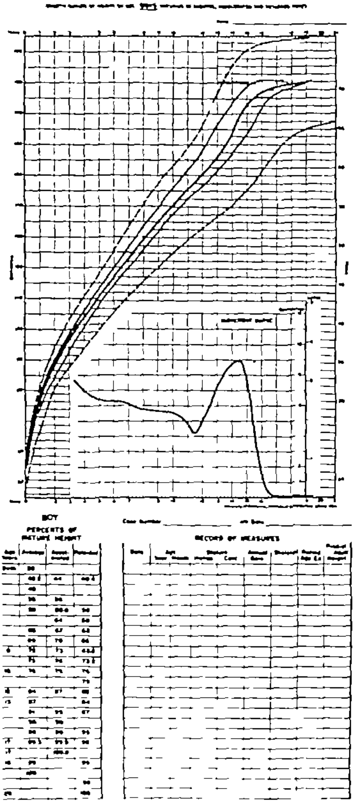


Fig. 189 Method of measuring and determining percentages of growth in the goat and in man. (From Bisgard, J D and Bisgard, M E.: Arch. Surg 31: 568 1935)



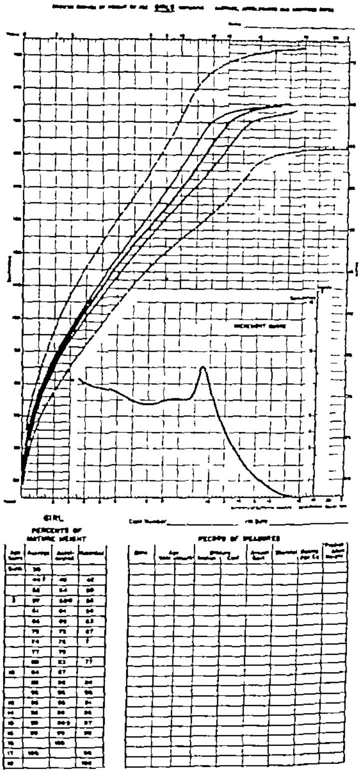


Fig. 190. Nancy Bayley stature graphs. These may be procured from the University of California Growth Study, Berkeley, California. (From Bayley, N.: J. Pediat. 48: 187, 1956.)

ent foramen pointed to the ends of each bone. The existence of more than one foramen may account for variables.

Table II Mean Percentage Growth at Each Epiphysis for Bone Involved

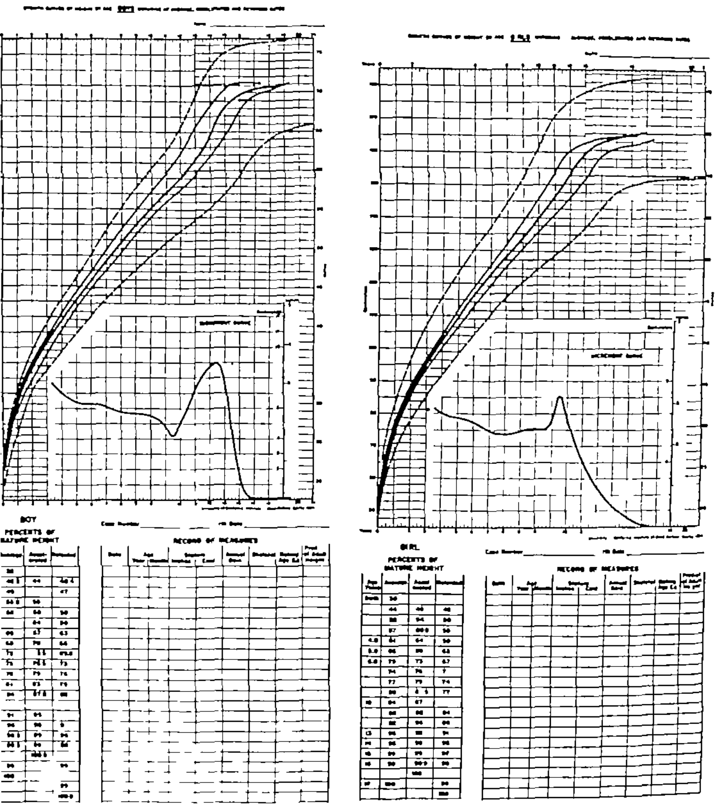
	Femur		Tibia	
	Upper	*Lower*	*Upper*	*Lower*
Digby 1916	31	69	57	43
Hatcher 1934	17	83	56	44
Bisgard 1933	36	61	56	44
Wilson and Thompson, 1939	30	70	60	40
Gill and Abbott, 1942	30	70	55	45
Hendryson, 1945	29	71	56	44
Hodgen and Frantz, 1946	23	77	55	45
Green and Anderson 1947	30	70	55	45
Goff 1957	28	72	55	45

The subject of growth prediction was carefully reviewed by Gill and Abbott.[19] Their calculations were based on Nancy Bayley's longitudinal growth series of California children (Fig 190) Her stature and weight prediction graphs are used at Newington and were published by her in 1956. This is not preferred when computing extremity growth. A modified graph is used for stature expectancy These values have been adjusted to Connecticut's child population from my studies [11].

According to Gill and Abbott, mean figures for total leg length cannot be applied because of wide variations in final length in individual cases such as 9.5 inches in boys and 7.5 inches in girls. Furthermore there is no constant ratio of total leg length to total stature. They considered that too little allowance is usually made for variations in sex and in skeletal maturation. It is well recognized that there is a poor correlation between the final height of a child and parent's stature while there exists a much closer correlation between a child's height and that of other children of the same age. Other authors had erroneously presumed that long bones grow at the same relative rate during the entire growth period, whereas in boys the femur grows slowly during the juvenile period and relatively more rapidly just before puberty Gill and Abbott take this into consideration. Their method of calculation consists of nine separate mathematical steps. They were based upon percentile measurements of a large sample of normal children chronological and relative proportions of the femur and tibia, compared with mean values and the final predicted stature of the patient Bone age ratings are used throughout—*not chronological age* Percentiles of stature are important values. Their chart is reproduced with modifications for Newington children based on several hundred determinations (Fig 191) This method has been used at Newington for many years with success as reported by Goff [1] A new work sheet has recently been added as part of the child's permanent record.

White and Stubbins[29] reported their results in 250 cases of epiphyseal arrest, believing that the numerous theoretical aspects proposed by others were of little practical significance. This series gave ample opportunity to observe the actual results with the corrections previously predicted. The method of growth prediction, which they found reliable was "absurdly simple" to use their words. Practical evidence showed that the arrest of the distal femoral epiphysis of the normal leg of the average child retards growth three-eighths of an inch (0.94 cm.) per year while arrest of the proximal tibial and fibular epiphyses causes a retardation of one fourth inch (0 6 cm.) per year White determined these amounts of growth by measuring the distance of growth arrest lines from their near-by epiphyseal discs and dividing by months elapsed since occurrence of the disease which provoked these dense metaphyseal markings. (Fig 192.) By calculating attainment of full growth at age 16 years for boys and 15 years for girls, the optimum time for surgical intervention in a given case was determined. White and Stubbins admitted that possible objections to such a broad approach to delicate mechanisms (growth centers) might be raised but their results appeared to fully justify their method. Absolute equality in leg length may be desirable but it is not a practical goal. A discrepancy measured in fractions of an inch gives an excellent functional result.

Dalton and Carpenter[8] discarded charts because they failed to get as much correction as anticipated from them. They now arrest at age 9 to 10 years—never before 8 years of age, when (according to them) epiphyseal structures are too soft and staples cut out. They prefer the distal femur alone and remove staples when the length discrepancy has been overcome. They believe that growth continues at the same rate *after removal. A temporary stimulation may follow after staples are removed, but* this is compensated by six months earlier closure of that epiphysis. *They report that staples in place* for three years will *not stop* a renewal of growth upon their removal, but that longer stapling will take out all the capacity for regrowth.



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An unusually good method by Stinchfield, Reidy and Barr[33] represents a tremendous amount of careful anthropomorphic measurements, complemented by measurements on orthoroentgenograms. After the acute stage of poliomyelitis the muscle power gradually *improves for eighteen to twenty four months*. Following this period there is usually little change in the muscle pattern. It appeared to them, therefore that prediction of shortening could be based on muscle examinations made two or more years after the onset of the disease Although the prediction of growth or lack of growth is subject to many individual variations, it was anticipated that clinical application could be made of the relationship between muscle power and shortening found in their study To predict the amount of shortening muscle examinations by the Lovett method should be made *two or more years after the onset of the disease*. These muscle ratings are given as normal (5) good (4) fair (3) poor (2) and trace (0) In this respect a "normal," or an extremity that had normal muscle power was considered somewhere between 111 and 115 Some twenty four to twenty five muscles are listed in their report, for

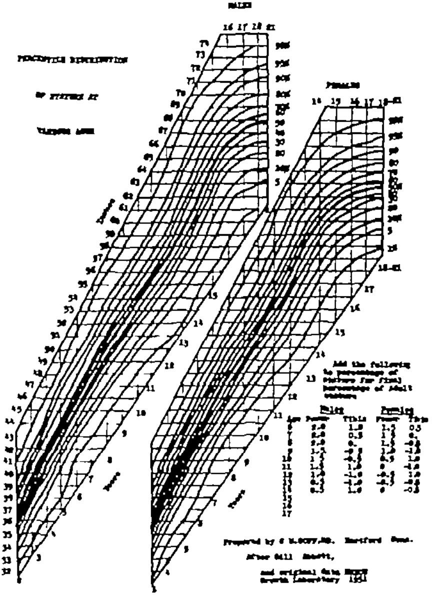


Fig 191 Newington stature graph percentiles. Prepared after the Gill and Abbott graph, with corrections for Connecticut population. Proportional percentages to be used in computing expected growth have been modified to conform with studies of Newington children. (From Goff C W American Academy of Orthopaedic Surgeons, Instructional Course Lectures, Ann Arbor 1951 J W Edwards, vol. 8 pp. 160-168)

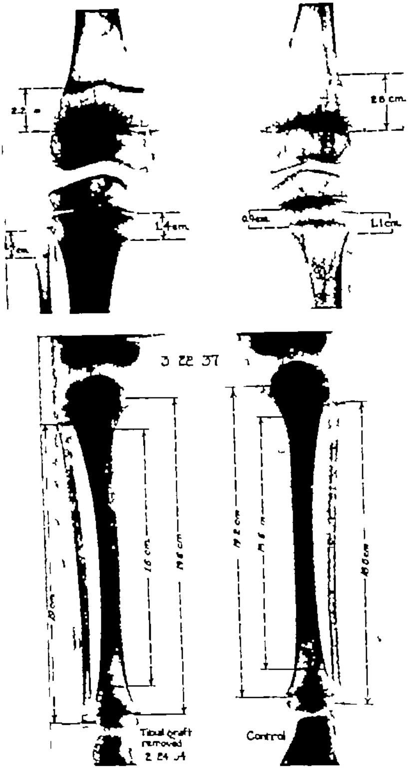


Fig 192. Two methods of measuring amount of and percentage of growth at an epiphysis by means of growth arrest lines. Many investigators have used the same technique. It is less accurate than markers placed intentionally (From Compere E. L., and Adams, C. O.: J Bone & Joint Surg 19: 922, 1937.)

*Table 12 Shortening of Lower Extremities Affected by Poliomyelitis Related to Muscle Power**

Left Extremity	Right Extremity 115-111	110-91	90-71	70-51	50-31	30-11	10-0
	Cm.	Cm.	Cm.	Cm.	Cm	Cm.	Cm.
115-111	0 8	1.2	2.3	4.0	5 8	6.4	6.7
110-91	1.2	1 0	1 6	9	4.5	5.5	6.3
90-71	2.3	1 6	0.5	1 0	3 0	4 8	5 8
70-51	4 0	2 9	1 0	0.8	1 4	.9	3.8
50-31	5 8	4.5	3 0	1 4	0 3	1 4	2.0
30-11	6 4	5 5	4 8	2.9	1 4	1.3	1.3
10-0	6 7	6.3	5 8	3 8	2 0	1.3	0 4
	1.5 Cm. -One Standard Deviation						

From Stinchfield, A. J Reidy J A., and Barr J S.: J Bone & Joint Surg 31-A: 478 1949

use in obtaining the score Their method requires an excellent knowledge of muscle anatomy and a capacity for testing quantitatively By use of their table the shortening of lower extremities affected by polio could be predicted from the score of the muscle power of the involved extremity This table (Table 12) is not hard to apply The standard deviation was 1.5 cm. Stinchfield and co-workers recommended that only in cases of poliomyelitis occurring before the age of 11 years should this chart be used, as the cessation of growth occurs at some variable time after this age. It was noted that the earlier the attack of poliomyelitis occurred in the child's life, the greater was the degree of shortening that ensued, if the muscular power was accordingly diminished. In discussing the paper Green reports that 20 per cent of his cases in girls had no longitudinal growth after the age of 13 years. He brings out that no constant coefficient appears feasible, concluding that no method is very dependable. He believes that growth is affected to a variable degree by the disease, depending upon the duration and onset. In this series the average maximal inhibition occurred from the second to the fifth year after the onset of the disease that is, there was less inhibition prior to the second year and after the fifth following the onset of this disorder This method must be studied carefully before it can be applied.

PREDICTED CORRECTION FROM EPIPHYSEAL ARREST

1949 REVISION

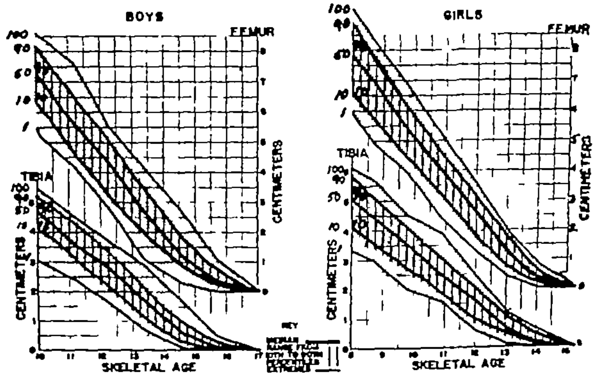


Fig 193. Graph of expected extremity growth, by percentiles (Redrawn from Green, W T and Anderson, M American Academy of Orthopaedic Surgeons, Instructional Course Lectures, Ann Arbor 1951 J W Edwards, vol 8, pp. 294-305)

Fig 194 Method of measuring stature. Patient stands against wooden, sliding measure marked in inches and centimeters. Heels, buttocks, dorsal spine and occiput are pressed against the wall. Block is lowered to firmly touch vertex. Patient steps forward one pace to permit reading of figures on scale

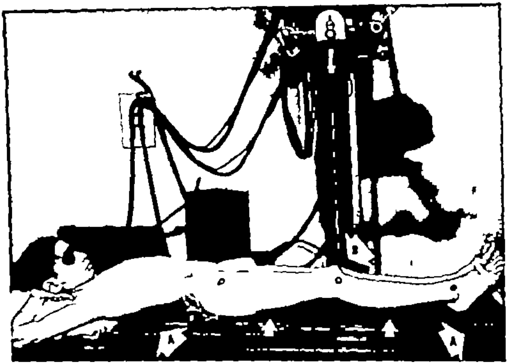


Fig. 195. Newington's method of taking orthoroentgenograms, modified: three spaced exposures, film 36 by 14 inches in a special cassette exposing hips, knees, or ankles in separate areas. Patient does not move A weighted string indicates central ray marked on film for each joint. (Designed by Dr A. V Nevulis.)

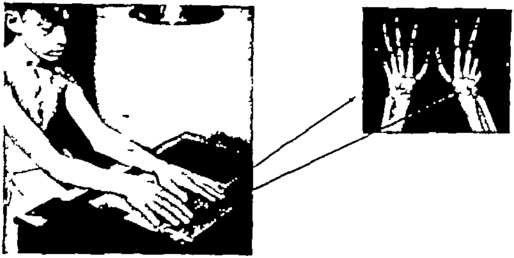


Fig 196. Method of taking hand plates for bone ages. (From Goff C. W.: American Academy of Orthopaedic Surgeons Instructional Course Lectures, Ann Arbor 1952 J W Edwards, vol 9 pp. 73-84.)

As far as I can learn from their report[4] and through personal communication, Blount and Clark do not use any particular predictional method, but state that "all furnish valuable help in planning stapling operations."* Somewhat earlier they state that "the operation [stapling] should be performed several years earlier than appears necessary from the actuarial charts and convenient to the patient the exact date makes little difference,"* because the staples are removed when they have done their work of equalizing the extremities. In 1957 Blount recommended stapling to equalize inequalities of as little as 1 cm. "if there is any disfigurement or discomfort."

There are not many surgeons who are temperamentally suited to "play it by ear." A more accurate system of computing expected growth has been needed. This should be developed after a sufficient amount of careful anthropometric data has been accumulated. Such basic material of unquestioned validity is represented by the Green and Anderson data (Fig 193). As they increase their numbers of individual determinations, so will their accuracy increase. Their chart has been simplified by giving the mean with the range of expected growth for the femur and tibia in boys and in girls. (Their prediction of expected growth is about 15 per cent more optimistic than that of the Gill and Abbott method.) Gill and Abbott's system is recommended for resident training. It presents to the learning house officer reasons and percentages that bring to the surgeon a greater understanding of growth processes.

Goff's Calculations of Growth. These have been determined by measuring many orthoroentgenograms, with steel markers present (Fig 197) which had been inserted by several methods, all of which are essentially innocuous. This provided an accurate system. The results are summarized in Table 13.

Table 13 Mean Percentage of Growth Calculated by Goff

	Fem	Tibia
Proximal	28	55
Distal	7	45

Table 14 Methods Used and Preferred for Predicting Lower Extremity Growth

	First Choice	Second Choice
Green-Anderson	62	22
Baldwin-Hatcher	12	6
Hogden-Frantz	1	—
Digby	—	—
White	16	4
Gill-Abbott	1	4
Straub-Thompson-Wilson	8	—
Stinchfield-Reidy Barr	10	2
Others	14	—
Skillful guessing	4	
No experience	6	—
Total responses	145	38
Total mailed	200	

Results of Questionnaire. In response to a questionnaire sent to many children's centers where ex

* From Blount W P and Clark, G R J Bone & Joint Surg 31 A 464 1949

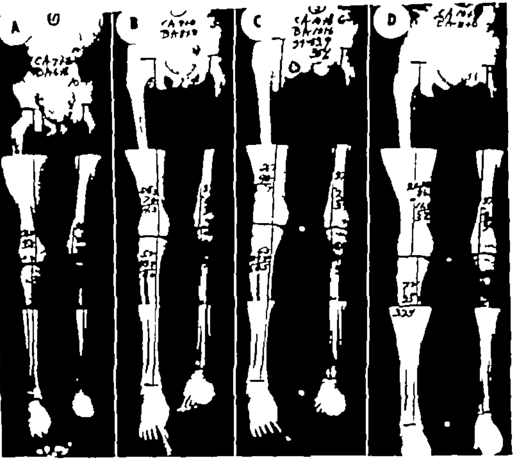


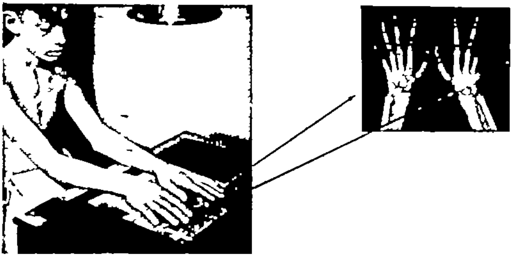
Fig 197 Goff's method of determining percentages of growth. Stainless steel markers are pounded or drilled through entire cortex, above and below knee joint epiphyses. Black lines show zones measured.

Case C. R. Male. Poliomyelitis at age 4 + 0 years. Determinations over 4 years show greatest deceleration in tibia. Percentages were computed as follows

	A to B =		B to C =		C to D =	
	Right	Left	Right	Left	Right	Left
Femur						
Upper	1.3 = 31%	1.4 = 36%	0.0 = 0%	0.0 = 0%	0.0 = 0%	0.2 = 15%
Lower	2.7 = 69	2.4 = 64	2.0 = 100	1.6 = 100	2.0 = 100	1.2 = 85
Tibia						
Upper	1.8 = 70	1.0 = 60	1.1 = 73	1.4 = 77	0.9 = 48	0.7 = 55
Lower	0.8 = 30	0.7 = 40	0.4 = 27	0.8 = 23	1.0 = 52	0.5 = 45

Upper femoral average = 13.6% lower femoral = 87.4%
Upper tibial average = 63.8% lower tibial = 36.2%

This is a typical example of the ebb and flow of epiphyseal disc growth percentages in poliomyelitis. This variation also occurs in apparently healthy children. Growth rate is never constant.



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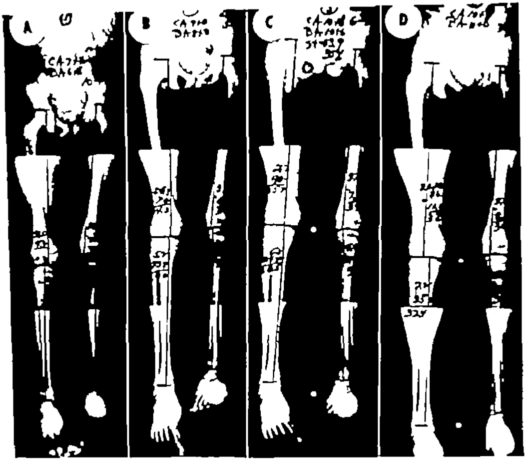

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Upper femoral average = 13.6% lower femoral = 87 4%
Upper tibial average = 63 8% lower tibial = 36 2%

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Table 15 Work Sheet Used at Newington for Computing Expected Extremity Growth

Name____________________ Male____ Female____
Case number________________ Birth date________
Height____________________ Inches or centimeters
Percentile____________ Weight______________
Chronological age_____ Bone age _____ (G & P Atlas)
Orthoroentgenographic lengths in inches or centimeters___

Total length of extremity R	L	Femur only R	L	Tibia only R	L	Difference

Femoral per cent of stature = $\frac{\text{Length of long femur} \times 100}{\text{Height}}$

Tibial per cent of stature = $\frac{\text{Length of long tibia} \times 100}{\text{Height}}$

Expected total stature = __________ (prepared chart)

Femoral per cent of adult stature ± Age factor = X_____
Tibial per cent of adult stature ± Age factor = Y_____
Final femoral length = X% × Expected total stature = A______
Final tibial length = Y% × Expected total stature = B______
Expected femoral growth = A − *Orthoroentgenogram* length of femur = C______
Expected tibial growth = B − Orthoroentgenogram length of tibia = D______
Expected growth, distal femur = C × 72% = E______
Expected growth, proximal tibia = D × 55% = F______
Epiphysis to be stapled _______ for _______ years
Epiphysis to be permanently arrested __________

Green and Anderson's Expect d Arrest
Lower femu ____ Upper tibia_______

tremity growths are calculated for equalizing tabulations indicate a fine acceptance of Green and Anderson's, as well as Gill and Abbott's methods of prediction. Most European centers are using Green and Anderson's system.

A more detailed summary of responses is presented in Table 14

Newington Methods. These have been published in former Instructional Courses in 1951 and 1952. They have been slightly modified, as is nearly always the case if updating is attended to In outline form, they include use of the following items.

1 Chart, with stature weight chronological age sex, and usually the racial stock of parents. Bayley Graphic Sheets (Fig 190) or those from the Children's Hospital, Boston, are recommended.

2. Hand and wrist maturation x ray plates for bone age (see Greulich and Pyle [**]

3 Orthoroentgenograms for lower extremity measurements. Green and Anderson technique with modifications, every six months on an average. The gonads are protected with a lead shield.

4 Flat upright spinal plates. Several views, some bending left and some right, to demonstrate spinal physiology 14 by 17 inch plates. These have been discontinued of late, as a routine, and are now taken on a selective basis.

5 Constitutional photographs, three views (Shelden technique)

6. Dental appraisal charts for eruption rates.

7 X ray studies of any important organ or extremity Special photographs are taken for the plastic surgeon clubfeet are studied in close-ups, and cerebral palsied children in gait motion pictures.

8. Predicted growth of lower extremities left and right, including expected final stature, is computed on the work sheet, a sample of which is given in Table 15

SUMMARY

The need for accurate observations and measurements of the growing child has been emphasized. In order to arrest or decelerate growth of an extremity this knowledge is necessary The *timing* of such control methods is most important.

Methods of obtaining growth dimensions are discussed, together with preferred ways and simplified means of estimating the proper epiphyses to decelerate for equalization. A growth team is recommended for best results.

This material is adapted from a monograph by Goff C. W., entitled Handbook: Control of Human Epiphysial Growth, Including Surgical Treatment of Unequal Extremities, to be published by Charles C Thomas, Publisher Springfield, Ill.

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OSTEOMYELITIS

In September 1889 W. R. Townsend of New York presented at the third session of the American Orthopaedic Association a paper on the subject of "Acute Arthritis of Infants." This paper is the first publication on pyogenic infections to appear in what is now the *Journal of Bone and Joint Surgery* I mention this publication because Townsend's discussion of the terminology pathology pathomechanics, bacteriology symptomatology the principles of treatment of the acute lesion, and its end results still holds true The subsequent sixty-nine years saw the elaboration of our understanding of the nature of the disease its bacteriological aspects, and the rise and fall of various medications and regimes of therapy for the osteomyelitic lesion. Townsend stated that no better advice could be given than that of Holmes, who had stated in 1869 that "acute joint disease leads directly and in childhood almost inevitably to abscess and it is in my opinion very important that this should be opened at the earliest possible moment." Can we in 1958 give better advice? Let us see!

ACUTE HEMATOGENOUS OSTEOMYELITIS

The time allotted to this presentation precludes, much to my regret, a detailed discussion of the elaborations of our increased appreciation of acute hematogenous, postacute hematogenous, and chronic osteomyelitic lesions. Certain basic knowledge well known to you must nevertheless be reviewed in order to fully rationalize the present-day concepts of the therapy of acute osteomyelitis. The vagaries of the osteomyelitic lesion and its clinical course are a reflection of the nature of the structure circulation, and physiology of the bones which provide the soil for the invading microorganisms In addition to the local and systemic responses of the host to the infection. It is therefore essential to the evaluation of the etiological factors and pathogenesis of the lesion to review certain aspects of the anatomy and physiology of bones which have not attained full growth.

Anatomical Considerations. The long bone presents a diaphysis of a relatively thick cortex enclosing a medullary canal. In the metaphysis the cortex becomes thinned most noticeably at the junction with the epiphyseal plate and encloses a mass of spongy bone. In the infant the metaphyseal cortex may be paper thin and the sponginess of the interior is relatively greater The epiphyseal plate is cartilaginous and presents the changes incidental to growth. The interior of the epiphysis beyond the epiphyseal plate consists of spongy bone surrounded by resting and growing cartilage, and its perimeter when full-grown consists of a thickened plate of bone upon which is superimposed a cover of articular cartilage. The entire bone is enclosed in a tubular sheath of periosteum, the attachments of which are firm only at the areas of contact with the epiphyseal plates and articular extremities and are loose throughout the rest of its extent. The flat bone, in contrast to the above presents thin cortices enclosing spongy masses of bone. The delineating periosteum is loosely adherent throughout save at epiphyseal or apophyseal attachments.

Circulatory Considerations. The blood supply of the growing long bone consists of three distinct groups of vessels. The first consists of one or more nutrient arteries which perforate the cortex at about the middle of the shaft and then subdivide into ascending and descending branches. Each of these subdivides many times in the medullary canal and metaphysis and terminates at the epiphyseal plate in very narrow and tortuous capillaries which, after looping back from the epiphyseal plate margin, form large venous sinuses. From these the venous capillaries arise and coalesce to form the veins in the medullary canal. This anatomical arrangement results in a pronounced slowing of the rate of flow of blood at the junction of the epiphysis and metaphysis. The second group of vessels, which consists of many small arteries, arising in the surrounding soft tissues and perforating the periosteum, supplies the superficial layers of the cortex of the shaft and its metaphyses. These vessels anastomose with those of the nutrient artery group. The third source of blood supply consists of several vessels which enter the reflected joint capsule to nourish the epiphysis. Since the epiphyseal plate is completely avascular during the growth period, there is no anastomosis between the epiphyseal blood supply and that of the rest of the bone.

It is opportune at this point to recall Robert W. Johnson's study of the blood supply of the diaphysis and metaphysis in which he showed that destruction of the periosteal vessels results in the loss of viability of the superficial layers of the cortex and that periosteal repair of the cortical defects is poor and delayed. More significant is the work of Ralph M. Larsen,[a] who showed that massive diaphyseal bone necrosis results from ischemia produced by increased intramedullary pressure. The significance of these findings in relation to the therapy of the acute osteomyelitic lesion is self evident and will be referred to again when that aspect will be discussed.

Physiological Considerations. Thought should now be given to certain physiological considerations which play important parts in the etiology of the osteomyelitic lesion. The concept that rapidly growing tissues, in contrast to mature tissues, are more susceptible to noxious influences is most important in the understanding of this lesion. The rapidly growing areas between the metaphyses and the epiphyses of the long bones during adolescence and in the epiphyses during infancy are no exceptions to this rule. Clinical substantiation can be found in the fact that the osteomyelitic lesion is located most frequently at the sites of greatest growth activity, namely: the epiphyseal structures in infants, the metaphyseal areas of young children and adolescents, and in rare instances the subperiosteal areas of adults, which retain some measure of bone growth activity during adult life. This is further substantiated by the findings that the sites of greatest frequency of metaphyseal lesions are at the sites of greatest growth: the lower end of the femur, the upper end of the tibia, the lower end of the tibia, the upper end of the humerus, etc., as indicated in the many published orders of frequency of localization.

It has been shown that bacteremias may occur in healthy individuals without untoward results, either because of the efficiency of the defensive mechanisms of the host or because of lack of pathogenicity of the microorganism. It has also been shown that the experimental introduction of microorganisms of sufficient volume and virulence may cause death from sepsis without bone involvement or abscess formation. The clinical counterpart is encountered in those instances in which death results before frank bone lesions can be recognized. A less virulent and less concentrated experimental bacteremia may produce lesions such as one sees in clinical instances.

Hypotheses of Pathogenesis. There are two hypotheses advanced to explain the pathogenesis of the osteomyelitic lesion. One school of thought believes the lesion to be the result of a thromboarteritic and a thrombophlebitic process. Minute conglomerations of organisms capable of passing through the relatively large capillaries of other tissues become blocked in the narrow, tortuous, inelastic capillaries of the metaphyses, giving rise to a local focus of disease. If the embolus is large, correspondingly larger vessels become blocked and involve larger areas in the process. Clinical and experimental observations do not seem to substantiate this theory.

The second school of thought believes in the concept that an osteomyelitic lesion arises because of an inadequate defense mechanism at the site of localization. It has been shown in experimental animals that soon after the intravenous introduction of microorganisms, colonies of these organisms are found in large numbers in the medullary canals and in lesser numbers in the metaphyses. Several hours later these findings are reversed, in that the colonies are fewer in number in the medullary canals and greater in the metaphyses. These phenomena

are thought to be related to a less active phagocytosis in the metaphysis a slowing up of the blood stream due to the physical arrangements of the blood vessels, a diminished oxygenation in these areas incidental to the growth processes, and a greater susceptibility of rapidly growing tissues, with the result that the enlargement of the foci and multiplication of the bacteria are more readily possible here than elsewhere in the bone. The clinical finding that the greatest frequency of the osteomyelitic lesion is in areas of greatest growth activity lends credence to this belief

Pathomechanics. Once a local focus has become established, there rapidly develops a local inflammatory process, with suppuration and abscess formation, in response to the rapid multiplication of the microorganisms and the production of their exotoxins, necrotoxins, leukocidins, and hemolysins and of the spreading factors (hyaluronidase) A "walling off" process sets in early in the form of a peripheral thrombophlebitic and thromboarteritic process, while the central area of the focus undergoes necrosis and suppuration. The important consideration in this process is that the abscess develops in rigid-walled surroundings, and the resultant accumulation of pus under pressure aids in the growth of the lesion by interference with the blood supply in the adjacent metaphyseal and subperiosteal areas. The local lesion becomes extended by way of the Haversian canals into the subperiosteal spaces, whence it may burrow under the periosteum to re-enter the bone through other Haversian canals or perforate the periosteum and burrow through the tissue planes until the overlying skin is perforated. Intra articular discharge of pus occurs in those instances where the point of perforation lies within the adjacent joint areas. In those instances where the perforation occurs in extra articular areas, accumulations of sterile fluid may develop in the adjacent joint in response to the proximity of the infection.

Bacteriological Considerations. The characteristics of the invading microorganisms play an important part in the inherent nature of the osteomyelitic lesion Any pus-producing organism may produce the lesion in question. The most common is the coagulase positive staphylococcus, which enters the blood stream via some skin lesion, such as an abrasion, a blister a cut, or a furuncle. The next most common invader is the streptococcus which may enter the blood stream from a focus in the upper respiratory tract tonsils, sinuses ear infections, or as a complication of the exanthemas such as scarlet fever or measles. Rarely lesions are produced by the typhoid and paratyphoid group of organisms.

Bacteria produce disease by virtue of several attributes described by the terms invasiveness and toxigenicity Invasiveness is the ability to invade the body to produce a local abscess, cellulitis, lymphangitis, adenitis, bacteremia, and secondary foci, as in the subject under consideration the osteomyelitic lesion Toxigenicity is the ability to produce toxins, such as erythrogenic or rash-producing toxins, lethal toxins, necrotoxins, hemolysins, and leukocidins. Both the streptococci and the staphylococci can be subdivided into many groups, each characterized by variations in the preponderance of the invasive or toxigenic characteristics. Thus, in the instance of erysipelas or scarlet fever the toxigenic factor is the more important, while the invasive factor—though it is essential, because toxigenicity cannot occur without invasiveness—is of relatively little clinical significance. On the other hand in osteomyelitis, the invasive character is the predominant factor while the toxigenic quality though it may be striking at the onset, soon recedes to the background in nonfatal cases. The same considerations hold true in staphylococcal osteomyelitis. The invasiveness is the outstanding characteristic, while the toxigenicity though it may be pronounced at the onset and striking and predominating in the fatal cases, soon recedes. During recurrences and upon the appearance of new foci in the chronic phase the toxigenic factor seems to be of little importance.

In addition to the invasive and toxigenic attributes there is an additional attribute spoken of as the "spreading factor" now known to be hyaluronidase, contained in the bacterial cell of the invading organism. This spreading factor varies with the invasiveness of the organism and increases the infectivity of heterologous and homologous bacteria by increasing tissue permeability to the infecting organism. The importance of the spreading factor in the rapid spread of a lesion locally or in the production of multiple lesions is readily evident.

Clinical Observations

The clinical picture of the acute hematogenous osteomyelitic lesion is composed of both systemic and local components and varies with the variations of the toxigenic, invasive and spreading factors of the offending microorganisms, and with the resistance and defensive processes initiated by the host. All of these elements are of course modified by the administered therapeutic procedures.

The toxigenic factors may manifest themselves in the symptom complex by (1) cutaneous erythema, (2) sustained elevation of temperature (3) persistently rapid and thready pulse (4) prostration (5) cold and clammy skin, (6) vomiting and diarrhea, (7) convulsions, and (8) death.

The invasive elements are manifested in the symptom complex first at the point of entry i.e. at the primary focus, which at times is difficult to recognize second, at the time of the systemic invasion with resultant systemic manifestations and third at the time of fixation and development of the secondary and subsequent foci forming the osteomyelitic lesion.

At the point of entry the manifestations may be (1) cellulitis, (2) abscess, (3) lymphangitis, (4) lymphadenitis, and (5) lymph node suppuration.

At the time of systemic invasion the manifestations may be (1) chill, (2) spiking or picket-fence temperature, and (3) positive blood culture.

The secondary or the osteomyelitic focus is characterized by the following: (1) spontaneous, boring pain, usually sudden in onset and localized, commonly to a metaphyseal and less frequently to an epiphyseal region (2) disability (3) localized tenderness over a metaphysis or an epiphysis (4) a moderate grade of painless passive motion in the neighboring joint (5) local heat (6) diminution of pain when the abscess perforates the periosteum and thereafter (7) redness (8) swelling (9) fluctuation and (10) sinus formation.

Clinically acute hematogenous osteomyelitis may be classified into four groups, depending upon the relative predominance of the toxigenic, the general invasive, and the secondary local factors namely: *(1) the fulminating*, (2) the severe acute, (3) the ordinary acute and (4) the mild type.

The fulminating type of acute hematogenous osteomyelitis is characterized by a profound and overwhelming toxemia (toxigenic factor) and septicemia *(general invasive factor) There is* pronounced collapse shock, cold and clammy skin, rapid pulse, a high maintained fever and possibly chills, convulsions vomiting diarrhea, and positive blood culture. In the recent past many of these *patients died, regardless of treatment administered* before any definite evidences of a local osteomyelitic lesion appeared.

The severe acute type of hematogenous osteomyelitis presents a picture that is somewhat milder than that described above. *In addition there are* now slight but definite signs of a local osteomyelitic lesion (local invasive factor) This type may become fulminating unless prompt and efficient therapy is administered.

The ordinary acute type of hematogenous osteomyelitis is the most common variety encountered. It is characterized by evidences of a moderate systemic involvement both toxigenic and invasive, and very definite evidences of the localizing lesion in one or more bones.

The mild type of acute hematogenous osteomyelitis presents minimal evidences of systemic and local lesions and may at times be overlooked and passed by completely only to be recognized at a later date by its manifestations during the chronic phase.

It is hardly necessary to stress that if the condition is kept in mind the diagnosis of acute hematogenous osteomyelitis in the great majority of instances can be and should be readily made before x ray evidences appear This lesion can be easily differentiated from acute joint lesions by careful palpation to localize the sharply limited areas of pain and by the presence of a limited range of pain less motion in the joint in question. In acute pyogenic arthritis and other forms of acute arthritis, the tenderness is over the joint and its reflected synovial surfaces, and the slightest range of motion produces pain.

Therapy of Acute Hematogenous Osteomyelitis

The therapy of acute hematogenous osteomyelitis has been—and for that matter still is—the most controversial aspect of this lesion. If treatment is to be rational, it must be directed to control all of the components of the symptom complex the invasive factor both systemic and local, and the toxigenic factor With this in mind I shall discuss therapy under the headings of general systemic, specific systemic, and local treatment.

General Systemic Therapy General systemic therapy should consist of general supportive measures such as blood transfusions, increased fluid intake, rest, sedatives, and other measures for the comfort and support of the patient.

Specific Systemic Therapy Specific systemic therapy may be serological chemical antibiotic, or a combination of any of these modalities. Before entering into a discussion of individual approaches it is appropriate that certain general considerations be noted. The difference between the so-called "medical" and "surgical" infections should be kept in mind in order to evaluate the efficacy of systemic therapy Medical infections are inflammatory lesions

with little or no necrosis of tissues. The lesions remain in communication with the blood stream and may therefore be influenced by therapeutic agents within the blood stream. Surgical infections are characterized by necrosis, suppuration and a walling-off process, which greatly diminishes and eventually shuts off the blood circulation from the localized lesions, so that therapeutic agents contained within the blood stream may become ineffective because of inability to enter the local lesions. In the early phases of surgical lesions, before the tissues become thrombosed and necrotic, blood stream therapy may be effective *in combating the local lesions.* In the subsequent phases blood stream therapy becomes more and more ineffective in so far as the local lesions are concerned. This holds true for any therapeutic agent, whether it be of serological chemical, or antibiotic character. From these considerations it becomes evident that the timing of systemic therapy is most important in the control of the local lesion. It is further evident from the above that, notwithstanding the fact that blood stream therapy may be effective in overcoming the systemic manifestations, it may nevertheless remain ineffective in overcoming local lesions.

Serological Therapy Serological therapy encompassed the use of bacteriophages, antitoxins, vaccines, toxoids, and immunotransfusions. These agents and procedures have fallen into disuse because of their limited effectiveness and the present day availability of the more effective antibiotic agents. *One should, however keep in mind that* antibiotics have no effect whatsoever on preformed toxins present in the blood stream. These toxins can be destroyed only by the production of antitoxin by the host's defensive mechanisms or the introduction of antitoxin from without. Since staphylococcal and streptococcal toxins are no longer available, one must depend upon the host's ability to produce antitoxin and upon the use of appropriate antibiotics which exert an indirect effect by preventing the production of additional toxins, through their action on the invading microorganisms.

Chemical Therapy Chemical therapy dates back to the intravenous administration of such drugs as Mercurochrome and gentian violet which, after a short lived period of acclaim, fell into disuse because of deleterious effects. The use of sulfa drugs proved to be more efficient and these are at the present time being used effectively in some types of streptococcal, gonococcal, and meningococcal nonsuppurating lesions. The effectiveness of these drugs in osteomyelitis is not nearly so great. In the presence of blood stream infections these drugs may be useful, provided the organisms are sensitive to the particular drug in use. Since the introduction of the antibiotics, the value of these chemotherapeutic agents in the treatment of osteomyelitis has been lessened considerably

Antibiotic Therapy With the introduction of antibiotic therapy the treatment of acute hematogenous osteomyelitis has undergone profound changes and the results have been spectacularly improved. Antibiotics are not panaceas and their use must be *discriminate and rational, if they are to be effective.* Accumulated experiences have already delineated limitations in their usefulness on the one hand and, on the other hand, reactions in patients which may lead to undesirable complications or to the necessity for discontinuance of the use of the drug. Similarly improper use may lead to loss of the effectiveness of the antibiotic agents. The limitations of the effectiveness of the antibiotics vary with the specific antibiotic, the offending microorganism, the responses of the patient, and the nature of the lesion and its state of development.

Penicillin. It has been shown during the early experiences with penicillin that somewhat over 20 per cent of coagulase-positive staphylococci were naturally resistant to the drug. As the use of the drug increased this natural resistance was found to be increasing, to such a degree that some investigators now report 90 or 100 per cent resistance. In the *early days it was also found that of the* sensitive coagulase-positive staphylococci some 20 per cent developed resistance during therapy. This was especially true in the presence of open wounds or inadequate doses. Since strains with acquired resistance remain virulent, the value of continued use of penicillin in the given instance becomes very questionable.

Continued experience with penicillin has also demonstrated that some individuals from the outset, and others after repeated use develop allergic manifestations to the drug such as dermatitides of various types urticaria, angioneurotic edema aggravation of previously existing epidermophytoses, rises in temperature or acute allergic shock which occasionally has terminated in death. It is therefore evident that acquired resistance and, more especially the increasing natural resistance of the predominating organisms in the osteomyelitic lesion, in addition to the increasing allergic manifestations on the part of patients, present a progressively difficult stumbling

block in the way of effective therapy with penicillin. In view of these problems, I have in my own practice discontinued the use of penicillin.

Streptomycin and Dihydrostreptomycin The effectiveness of these drugs is generally conceded to be less than that of penicillin because of the more frequent natural resistance as well as the more readily acquired resistance on the part of the coagulase-positive staphylococci to these antibiotics. In addition, the toxicity of the drug which may manifest itself in the development of deafness, the disturbance of equilibrium, and various skin manifestations, make these unsuitable for routine use in staphylococcal infections.

Broad-Spectrum Antibiotics The discovery and development of these drugs—chlortetracycline (Aureomycin) oxytetracycline (Terramycin) tetracycline (Achromycin, Tetracyn, and others)—came in good stead and they have very largely replaced penicillin and the streptomycins in the therapy of the staphylococcal infections because of their greater range of effectiveness and the less consequential untoward complications which may arise from their use. At the outset there was no appreciable resistance to these drugs. Unfortunately this is rapidly increasing especially among hospital populations. The untoward reactions are chiefly of a gastrointestinal nature nausea, vomiting and diarrhea, which can in most instances be readily controlled by administering the drug on a full stomach, or by the temporary discontinuance of oral doses and their replacement with intramuscular or intravenous administrations. Notwithstanding the gradually developing deficiencies of this group of drugs they still remain the mainstay in therapy of the osteomyelitic lesion in so far as I am concerned.

Other and Newer Antibiotics It is fortunate indeed that new antibiotics are constantly being developed and introduced into the armamentarium for the therapy of the osteomyelitic lesion. Experience with some of them is not as yet extensive but is, nevertheless, sufficient to warrant their use. Of these drugs, erythromycin (Ilotycin) is reported to be the most effective. Oleandomycin (Matromycin) and carbomycin (Magnamycin) have in my practice been very useful in instances in which the offending microorganism was resistant to the broad-spectrum antibiotics. On occasion, chloramphenicol (Chloromycetin) has been quite useful especially in the typhoid or paratyphoid osteomyelitic lesions.

Combination of Antibiotics The most recent trend in the therapy of infections is the use of combinations of antibiotics and the considerations leading to their use have been enumerated as follows (1) to obtain better results because of alleged synergism of certain combinations (2) to lessen toxic effects, (3) to delay or prevent the emergence of resistant strains, (4) to combat mixed infections, and (5) to treat seriously ill patients promptly and before a bacteriological diagnosis can be made. This approach has met with considerable controversy. Experiments have been performed to prove the effectiveness or ineffectiveness of such usage and there are proponents and antagonists to such combinations. It would seem from the maze of experimental data that no definite rules can be established as yet and that sensitivity tests should be carried out in each instance to determine possible advantages. It is also apparent that combinations of narrow-spectrum antibiotics (penicillin and streptomycin) and broad spectrum antibiotics are likely to be disadvantageous, while combinations of penicillin and streptomycin may be more effective than one or the other. My own experience has been limited to the use of Sigmamycin (two parts Tetracyn and one part Matromycin) and P A 765 (two parts Terramycin and one part Matromycin). Though the clinical results were good I must admit that any of these lesions might have had just as good a result with the solo use of either one or the other antibiotic. Previous and subsequent experiences have given just as satisfactory results with the use of individual drugs. Since, for very obvious reasons, controlled observations cannot be made in clinical practice with such a variable as the osteomyelitic lesion the final determination must come from other sources.

Timing and Intensity of Dosage In addition to the limitations that have been encountered with each of the above mentioned antibiotics, there is an additional and very important over all necessity in the effective use of any of these drugs namely early timing and intensive dosage of the chosen agent. In so far as the local lesion is concerned the antibiotic must be administered in plentiful quantity before the lesion becomes walled off—in sufficient time to prevent the subperiosteal accumulation of pus, with its incidental disruption of the circulation of the cortex, and to prevent dangerously increased intramedullary pressure with its incidental massive ischemia of adjacent areas.

Results of Antibiotic Therapy Experience has shown that adequate antibiotic therapy of the acute hematogenous osteomyelitic lesion will produce results which can be readily classified into four groups.

1 Those cases in which complete subsidence of the systemic and local lesion occurs before roentgenographic evidence of the presence of the focus of disease has developed. These instances are diagnosed on clinical evidence only and at no time do they show x ray evidence of the presence of such a lesion. These are ideal results and are classified as aborted lesions.

2. Those cases in which there is complete subsidence of the systemic manifestations, accompanied by a roentgenographically demonstrable local lesion. These roentgenographic evidences regress, and the normal appearances are reconstituted. One cannot foretell this regression with certainty and the results are therefore not so desirable as those in the first group.

3 The third group consists of instances in which there is an effective subsidence of the systemic manifestations of the disease while the local symptoms persist and increase. In these cases local tenderness persists, and the swelling and redness increase in association with increasing roentgenographic evidences of progressing lesions. Eventually spontaneous drainage by way of a sinus will take place and the lesion will progress and develop the characteristics of the postacute stage. Notwithstanding the fact that the bacteremia will have been controlled, the local lesion will be positive bacteriologically

4 The fourth group of cases consists of those in which the systemic manifestations as well as the local lesions remain uninfluenced by antibiotic therapy If no other measures are instituted the patient will become more toxic and septic and will deteriorate rapidly terminating in death, or possibly will develop spontaneous drainage and the characteristics of the postacute phase.

Summary of Systemic Treatment. It is evident from the above that we have at our disposal for the specific systemic therapy of the acute hematogenous osteomyelitic lesion several effective antibiotics which in early and mild lesions may abort or even induce a regression of the local lesion. In other cases we find that the antibiotics cannot influence the local lesion because it has become walled off In still other instances the antibiotics cannot control either the systemic or the local lesions. In the latter two categories local therapy becomes imperative.

Local Therapy Immobilization of the involved extremity may be achieved in a compression bandage of sheet wadding flannel, and adhesive or a plaster of Paris support should be applied during periods of conservative or expectant therapy Such immobilization adds greatly to the comfort of the patient, diminishes the pain, and probably lessens the opportunities for spread of the lesion, by producing stagnation in the lymphatics. In the more extensive lesions pathological fractures may be avoided.

A consideration of the local pathological process in the light of experimental studies leads to an indication very significant in the local therapy of the acute hematogenous osteomyelitic lesion. Johnson[1] has demonstrated that the viability of the outer layers of the cortex of the diaphysis and metaphysis depends upon the integrity of the periosteal vessels. It therefore becomes evident that prevention of a subperiosteal accumulation of pus with its incidental disruption of the circulation of the cortex is important in order to prevent necrosis of the superficial layers of the cortex. Larsen[2] has shown experimentally that massive diaphyseal bone necrosis results from ischemia produced by increasing intramedullary pressure. This leads to the unavoidable conclusion that early decompression of the involved area is essential lest the bone become devitalized.

Nevertheless, there is still disagreement as to the time at which surgical intervention should be instituted, if at all, and as to how extensive it should be, when it is instituted. Granting that bacteremia and toxemia can in a large number of cases be controlled by medical approaches, it nevertheless seems illogical to follow the advice of those who would have the surgeon wait until the local lesion becomes most extensive and discharges spontaneously and, in those instances in which the bacteremia is not controlled, until a dangerously increasing bacteremia occurs, before he operates upon the local osteomyelitic focus. An operation for the prevention of such eventualities seems to be reasonable and preferable. The timing of an operative procedure is at times difficult. Prior to the introduction of antibiotics, operative intervention was considered an urgent necessity in many instances. Such urgency is presently not essential for opportunity should be afforded, especially in those patients with lesions of short duration to observe the effects of the specific systemic therapy with appropriate antibiotics in the hope that the local lesion may be influenced favorably The deciding factors are the symptoms and findings at the site of the local lesion.

The injection of antibiotics into the lesion has in my experience proved ineffective. I have noted a sterilization of the blood stream in the presence of systemic administration of the antibiotics of choice and at the same time repeatedly positive cultures

may be obtained from the local lesion, notwithstanding the large doses of the same antibiotic injected into the local lesion.

In view of all the above considerations it is my practice at the present time to institute antibiotic therapy at the earliest opportunity. In the severely ill patient an immediate intravenous infusion of 500 mg. of a broad-spectrum antibiotic in 1 000 ml. of normal saline is given and followed by the oral administration of 250 mg. of the drug every three hours. The 3 A.M. dose may be omitted if at midnight 500 mg. of the antibiotic are administered. The intravenous infusion may be replaced by the use of an intramuscular injection of the appropriate form of the drug.

If at the end of several days the local tenderness does not subside, surgical intervention is instituted. This consists of a simple incision, with due consideration to anatomical structures, several drill holes in the metaphysis and excision of a small window for the evacuation of the lesion. The site is then flooded with a solution containing 0.5 mg. of a broad-spectrum antibiotic per milliliter of solution, and the operative site is closed, without drainage, in several layers, each of which is flooded with the antibiotic solution. A dressing wet with the antibiotic solution is applied, and the limb is immobilized in a compression bandage of sheet wadding, flannel, and adhesive. The operative wound is left undisturbed until the tenth day, when the wound will practically always be found to have healed per primam. The compression bandage is reapplied for several weeks. If the lesion involves a lower extremity, no weight bearing is permitted for a period of several months. During the first four weeks of the postoperative period, antibiotics are administered as outlined above, 250 mg. every three hours.

Therapy in Infants. It is important to note that the treatment of acute hematogenous osteomyelitis in infants under 2 years of age should be somewhat different from that in the older age group. Several investigators have demonstrated that because of differences in anatomical structure, physiological and pathological reactions, and greater powers of repair, incision for evacuation of the abscess should at the very least be deferred until the infant is in suitable condition for operative intervention. The urgency for a surgical procedure is considerably less in this age group, due to the fact that the bone abscess is under less tension because the vascular spaces are larger, the proportion of soft tissue elements is greater, the bony element is less rigid, the metaphyseal cortex is almost paper thin, and the periosteum is more loosely attached. As a result of these anatomical differences spontaneous adequate decompression of the bone abscess usually occurs sufficiently early to prevent massive necrosis and the consequent sequestration. Furthermore, since the repair processes are much greater, whatever necrotic bone may result from the extensive subperiosteal dissection that usually occurs is rapidly absorbed by a process of autolysis. Because of these factors, the consequences of the local lesion are less serious than in the older age group, and therefore the urgency of early operative intervention is of less import. In fact, operative delay in this age group is advisable until such time as the general condition of the patient improves enough to make operative intervention more readily tolerated. Because of the adequacy of spontaneous decompression, soft tissue drainage may be all that is necessary and occasionally operative intervention may be entirely avoided. The early administration of antibiotics in adequate dosage, blood transfusions, and fluids will aid greatly in the attainment of most satisfactory results.

Therapy of Fulminating Cases. The principle of early decompression must be applied with great discretion, if at all, in the fulminating and severe acute types of osteomyelitis. The outstanding factor in these cases is the toxemia and septicemia and not the secondary bone lesion, which may at the outset, be very indefinite. Systemic treatment with antibiotics and transfusions should be instituted primarily, while surgical treatment should be withheld until definite evidences of a local bone lesion present themselves and persist despite specific systemic therapy.

Therapy of Primary Focus. A discussion of the therapy of acute hematogenous osteomyelitis would be incomplete without a consideration of the primary or distributing focus. Unfortunately, in the majority of instances the primary focus either is not evident or is already burnt out. Nevertheless, it is generally agreed that, in a case of septicemia due to pyogenic organisms, it is the surgeon's responsibility to locate the distributing (primary) focus and if possible to remove, evacuate or isolate it, in addition to the above-outlined systemic therapy and local therapy where indicated.

Results of Therapy. As a consequence of the regimen described above, healing has occurred in my practice in almost every instance. In those patients for whom timely surgical intervention—when needed—has not been instituted, the lesion has entered into

the postacute stage if the patient has survived the onslaught of the acute lesion.

POSTACUTE HEMATOGENOUS OSTEOMYELITIS

In the preceding discussion the rationale of therapy of the acute osteomyelitic lesion was presented. The success of the regimen of therapy will vary with a host of factors, depending upon the variable toxigenicity, invasiveness, and sensitivity or resistance of the offending microorganism, upon the ability of the patient to develop an appropriate defense against the invasion, upon the promptness with which antibiotic therapy was applied and, in those instances in which the medical approach was insufficient, the promptness with which surgical therapy was instituted both for the osteomyelitic lesion as well as for the primary focus if it was present. Those patients who do not recover enter what may well be termed the postacute phase, one which others have referred to as the "x ray stage," the second phase or the reactive stage of osteomyelitis.

Clinical Course

The postacute phase is characterized in many untreated or inadequately treated patients by a low grade fever, a slow but progressive downward course to ultimate exhaustion through increasing loss of body weight, anemia, the persistence of draining sinuses, the occurrence of pathological fractures, deformities, amyloidosis, and eventually death in some cases or the chronic phase in others.

Roentgenographic and Pathological Changes

The roentgenographic changes are marked and striking and depict the destructive and reparative processes that take place side by side. The diseased and adjacent areas undergo rarefaction incidental to the inflammatory process. The devitalized portion of the bone, having lost its circulation and become necrotic, retains its previous calcic content. It is therefore characterized by a relatively increased density when compared to the surrounding bone. Concomitant with the development of necrosis, there is resorption of the devitalized bone. This is usually only partially successful, especially so if the necrosis has been at all extensive. The reparative process is identified by periosteal proliferation to produce a protective cuff of bone or involucrum. As a result of the involucrum formation the bone becomes thickened and deformed. In addition there is an endosteal reparative process resulting in an intramedullary proliferation of new bone which eventually produces, in the later stages of this phase, an obliteration of the medullary cavity. As the reparative process progresses, the invading granulation tissue undergoes fibrosis with resultant gradual diminution of the blood supply. This is associated with increasing deposition of calcium and increasing density of the newly forming bone. Enclosed within this newly formed bone or bone scar are larger and smaller areas of infected granulation tissue, accumulations of pus, and sequestra. Further changes, beyond this stage of repair, progress more slowly unless an exacerbation or a lighting up of the process occurs. It is at this point—when the involucrum is well formed, when the walling off process is fully developed, when the involved bone is well calcified, and when the sequestrum formation is well defined—that the third or chronic phase of osteomyelitis begins. The demarcation between the postacute and chronic phases is, like the demarcation between the acute and postacute phases, gradual and not well defined. Its recognition is, however, important because of the therapeutic considerations. The duration of the postacute phase may extend over three or more months.

Therapy of Postacute Hematogenous Osteomyelitis

General Systemic Therapy. The therapy of this phase of osteomyelitis should consist of general systemic care to support the total well-being of the patient. It should include hygienic care, a high caloric and high vitamin diet, and whatever additives may seem appropriate. Secondary anemia should be combated from the outset with the use of hematinics, liver extracts, and transfusions.

Specific Systemic Therapy. Specific systemic therapy is on the whole ineffective and inadvisable. It is ineffective, since the antibiotic cannot reach into the focus of disease because of the walling off process which becomes more effective as the lesion becomes fully developed. Specific systemic therapy is inadvisable because of the great likelihood of development of acquired resistance on the part of the offending organism. This is especially true in the presence of open wounds which become infected with secondary invaders naturally resistant to the antibiotics in use. Repeated bacteriological observations have shown persistently positive cultures of organisms, notwithstanding the use of large doses of antibiotics. Sensitivity tests show that these organ-

isms either are sensitive because the antibiotic does not get into the focus or become increasingly resistant because inadequate amounts of the antibiotic enter the focus.

Local Therapy. The primary indication in the treatment of the postacute osteomyelitic lesion is the application of support, preferably in the form of plaster of Paris bandages, to prevent pathological fractures and deformities. Surgical intervention should be undertaken with great caution, if at all, because at this stage the involucrum may be made quate to maintain the support of the overlying structures and, second, because it is impossible to differentiate between that portion of the bone which is porotic incidental to the increased circulation of the inflammatory process and that which is porotic because of the destructive and devitalizing effects of the disease. To attempt to remove all apparently diseased bone at this stage would involve extensive removal of tissue and would expose the involved bone in the absence of protective involucrum, to pathological fractures and possibly to nonunion. In those instances in which the lesion is localized and in which there appears to be sufficient normal bone or involucrum to support the overlying structures, a saucerization and primary closure procedure should be undertaken in a manner that will be described under the therapy of chronic osteomyelitis. In those instances in which surrounding circumstances are not favorable one may have to be content with temporary procedures to improve drainage. These procedures should be performed under an antibiotic umbrella, to be described under the therapy of chronic osteomyelitis.

CHRONIC OSTEOMYELITIS

The line of demarcation between the postacute and chronic phases of the osteomyelitic lesion is not sharply defined, as has been noted previously. Its identification is, however, important because of the changed indications in the therapy of the lesion. The chronic phase begins with the development of a well formed involucrum, a fully developed walling off process which is characterized by endosteal new bone formation resulting in increased bone density and obliteration of the medullary canal, a reossification of the involved area which encloses sequestra and foci of bone rarefaction and bone condensation. Of all of these elements, the presence of an adequate involucrum is the most important indication in the undertaking of surgical therapy.

Clinical Course

Chronic osteomyelitis is characterized clinically by the persistence of one or more local lesions which appear to heal, only to become reactivated from time to time, and by the appearance of clinically new lesions which on roentgenographic examination prove to be of long duration. A clinically active lesion may be associated with general malaise, loss of weight, low-grade fever, progressive anemia, disability of varying degrees, boring pain (more evident at night), tenderness, redness, and, finally, the reopening of a previously healed sinus or the development of a new sinus. This train of symptoms and findings may at times subside without the development of a sinus, either without the benefit of therapy or during the course of nonsurgical therapy, regardless of its nature. Other lesions may present a persistently draining sinus with few or none of the symptoms mentioned above. There are yet other lesions which are clinically quiescent and which present no symptoms whatsoever. Repeated roentgenographic examinations of any of these lesions over a prolonged period of time will reveal a progressive extension of the lesion, regardless of its clinical state.

Therapy of Chronic Osteomyelitis

Clinical Considerations. The above clinical considerations are of the utmost importance in evaluating the effect of nonsurgical therapy. The mere subsidence of clinical symptoms is no indication of the effectiveness of such therapy, whether it be of a serological, chemical, or antibiotic nature, unless that subsidence is associated with roentgenographic evidence of the subsidence of the lesion. It is now well known that with the introductions of these various modalities some observers who were not fully cognizant of the above clinical facts had hoped for results similar to those achieved in conditions other than osteomyelitis, only to meet with grave disappointment. Some of their early results were good but, unfortunately, temporary and therefore misleading.

Pathological Considerations. Chronic osteomyelitis is characterized by the presence of a diseased bone and soft tissue coverings showing some changes incidental to the processes of destruction and some incidental to the processes of ineffectual attempts at healing.

The changes resulting from the processes of destruction are evidenced by the presence of variously

shaped and sized cavities containing frank pus, infected or indolent granulation tissue necrotic fibrous tissue and sequestra, in addition to areas of atrophic bone containing fibrous bone marrow These cavities may or may not communicate with the surface of the bone or limb by means of sinus tracts lined with dense fibrous tissue.

The changes resulting from the processes of ineffectual attempts at repair are manifested by subperiosteal and endosteal new bone formation with consequent partial or total obliteration of the medullary and Haversian canals and an irregular thickening of the cortex of the bone. These changes lead *to an over all deformation of the involved bone* and conversion of the diseased area into an ivory like mass of dense bone. The periosteal covering of such a bone is thickened, fibrous, and scarred as a result of the long-standing inflammatory process. The soft tissue cloak of such a bone is usually densely cicatrized and poorly nourished because of long-standing stasis of blood and lymph incidental to the chronic inflammatory process and prolonged immobilizations, and frequently because of scars of previous operative procedures and of intermittent healing of sinus tracts.

It is therefore evident that one of the most important characteristics of the lesion is its poor blood supply The contents of bone cavities, such as pus and sequestra, are completely avascular while the surrounding bone scar and dense fibrous tissue elements of the enclosed cavities, sinuses, periosteum, and over-all soft tissue layers are poorly vascularized.

The Inefficacy of Conservative Therapy These findings should leave no doubt as to the inefficacy of conservative therapy by way of medicaments which depend upon the blood stream for their deliverance into the focus. This holds true for all substances, including the various serological, chemical, or antibiotic products either known to date or likely to be produced in the future whose effectiveness depends upon intimate contact with the diseased area. The accuracy of this assertion is further supported by the observation that in no instance in my experience did increased resistance of staphylococci occur in patients treated by antibiotics without surgical intervention. notwithstanding the fact that it is now generally acknowledged that staphylococci which persist over long periods of time in wounds healing by secondary intention tend to develop increasing resistance to the antibiotics. The explanation lies in the fact that the material for culture in the conservatively treated patient was necessarily obtained from draining sinuses This leads to the conclusion that such organisms were not exposed to the administered antibiotic, because of the relatively avascular nature of the thickened fibrous walls of the sinuses and the avascularity of the lesion in which they originated. These considerations are further substantiated by the many clinical observations indicating failure to obtain lasting relief by conservative therapy

Surgical Therapy The failure of medical therapy of the osteomyelitic lesion notwithstanding the use of potent antibacterial substances points to the need for excision of the focus and the need for making possible the entry of the antibacterial substances into *the site of the focus. The problem is therefore two-fold* first, control of the infection and, second, removal of the focus of devitalized and poorly vascularized tissue. Mere control of infection, if it were possible, would be insufficient, for the persistence of the focus carries with it the possibility of a relighting of the focus and the development of symptoms. Furthermore the presence of infection is not an absolute prerequisite for the development of symptoms, as is indicated by the occasional finding of a sterile Brodie s abscess or a sterile sclerosing osteomyelitis.

It is now the general consensus that the required surgical procedure should consist of a saucerization of the involved area. To be effective this operation must be very thorough. It is my practice to do this operation under tourniquet control wherever possible, to excise all diseased tissue technically feasible, and to extend this excision to the normal medullary or metaphyseal areas at both extremities of the lesion—without elevating the periosteum beyond the area to be excised and without injuring adjacent epiphyseal plates or entering joints or destroying any important anatomical structures. The use of the motor saw in unroofing the bone expedites this procedure and lessens the shock. In addition, the soft tissue scar should also be excised to the extreme of surgical feasibility All recently used systems of therapy provide for a saucerization procedure as described above. Beyond this basic operative approach there are considerable variations in the aftercare, depending upon the system of therapy employed.

Problems of Repair of Surgically Treated Lesions. The necessity for surgical eradication of the osteomyelitic lesion gives rise to the difficult problem of healing the resultant rigid walled cavity The only exceptions are those parts which are subjected to amputations. Healing can be accomplished by one of two methods either primary intention or second-

ary intention. The usual method employed in recent times has been that of healing by secondary intention, which depends upon the filling of the rigid walled cavity with granulation tissue, arising from the depth and periphery of the wound to its surface and the subsequent epithelization of the excised areas. The success of this method hinges largely on the speed with which the cavity is filled with granulations. The pitfall of this method lies in the physiology of repair. The aging granulation tissue at the periphery of the wound becomes converted into fibrous tissue, as is characteristic of scar tissue formation. This results in the shutting off of the blood supply and eventual interference with further repair of the rigid-walled cavity.

The healing of the surgically eradicated lesion by primary intention has in the past depended upon various plastic procedures to obliterate the rigid walled cavity in association with primary or delayed closure of the wound. The use of muscle flaps and foreign substances to eradicate the dead spaces was ordinarily unsuccessful, because antibacterial agents hitherto available were inadequate to control the element of infection of the hematoma, which of necessity is part of the process of repair. Furthermore the presence of foreign bodies in infected areas is a deterrent to the subsidence of the infection.

It is apparent from the above considerations that the prerequisites for satisfactory healing of the chronic osteomyelitic lesion by secondary intention are the following: (1) a thorough surgical procedure to eradicate the lesion, (2) some efficient and harmless method of sterilization of the surgically formed wound, (3) some means of removal of wound discharge and sloughs that occur as a result of the infection and the surgical procedure, and (4) some agent that would produce an even and rapid growth of healthy granulations from the depth of the wound upward to cause complete filling of the bone cavity before the circulatory changes incidental to scar tissue formation develop with resultant loss of blood supply and cessation of further healing.

The prerequisites for the healing of the chronic osteomyelitic wound by primary intention are as follows: (1) a thorough surgical procedure to eradicate the lesion, (2) a method of primary closure of the surgically formed wound, and (3) an agent to control the infection until such time as the hematoma becomes sufficiently organized in the process of healing to resist infection.

The enrichment of our therapeutic armamentarium with antibiotics makes possible the fulfillment of the last and most important prerequisite for healing of the surgically produced wound by primary intention. The desirability and advantages of healing by primary intention are self-evident and one need hardly discuss the avoidance of suffering, the savings in time and expenditures, and the more satisfactory healing obtainable as compared to that resulting from healing by secondary intention. In view of the limitations of time we will not enter upon discussion of the rationale, results, and comparisons of regimes of therapy recently in vogue, namely, the Carrel Dakin, the Orr, the Bipp, and the maggot therapies, and their modifications. Occasionally in the face of inadequate skin coverage one may have to resort to the Orr method. Under all other circumstances primary closure should be undertaken, for the prospects of success are very high.

It should furthermore be noted on the basis of experiences presented elsewhere[3] that nothing is to be gained by the use of local and systemic antibiotics in patients with saucerized wounds which are to heal by secondary intention, because of (1) the failure of the antibiotic to exert a positive influence on the time element of healing by granulations, (2) the failure to control primary or secondary bacterial invaders, (3) the development of pronounced resistance to the antibiotic on the part of the primary invaders, (4) the relatively absolute resistance on the part of the secondary invaders, and (5) the not infrequent development of allergic manifestations on the part of the patient to the antibiotic.

Treatment by Saucerization and Primary Closure Under Antibiotic Control. My own experience with and practice of saucerization and primary closure under antibiotic control is the outgrowth of a research project begun in 1944 and continued through 1945 under the aegis of the Committee on Medical Research of the Office of Scientific Research and Development at the Hospital for Joint Diseases. Beginning with 1946 and continuing to date, the project has been fostered by several drug firms and the Hospital for Joint Diseases. A relatively large number of patients have been submitted with outstanding success to the following regimen of therapy for the chronic osteomyelitic lesion.

As a rule all antibiotic therapy is withheld until all investigative studies have been completed. In the presence of a discharging sinus, bacteriological studies with sensitivity determinations are included in the investigations, and the choice of antibiotic is thereby determined. In the event no bacteriological

information is obtainable, a broad-spectrum antibiotic is employed.

The administration of the chosen antibiotic is started twenty four to forty-eight hours prior to the operative intervention, the details of which have already been indicated. Every three hours, 250 mg are administered by mouth, omitting the 3 A.M. dose and doubling the midnight dose. During the course of the operative intervention 500 mg of the antibiotic are administered intravenously in 1 000 ml of glucose and water In addition the operative wound is thoroughly washed and flooded as it is closed, layer by layer with a solution of normal saline containing 0.5 mg of the antibiotic per milliliter of normal saline. The administration of the antibiotic is resumed as soon as the patient can tolerate oral medication after the operative procedure, using 250 mg every three hours, omitting the 3 A.M. dose and doubling the midnight dose. This is continued for a period of four weeks. In the event of intolerance because of gastric upset, intravenous medication of 500 mg per 1,000 ml of diluent is administered intravenously daily for several days, to be followed by oral medications as noted above. As an alternative the intramuscular form of the drug may be used (200 mg two or three times a day) The above modifications may also be used in the presence of diarrhea, which at times develops during oral medication. It may sometimes be necessary to change to another of the broad spectrum antibiotics because of these complications.

The surgical procedure is performed under tourniquet control whenever possible The tourniquet is not released until the part has been immobilized in a firm compression bandage of sheet wadding flannel bandages, and adhesive. This support is not disturbed for approximately ten days, at which time the wound will be found to have healed per primam. The skin sutures should be removed and the part repeatedly reimmobilized in compression bandages for a period of four weeks at weekly intervals. In the event of partial discharge of the hematoma no effort at milking should be made. The application of adhesive butterflies, dry dressing and compression dressings will result in satisfactory healing No drainage of the wound should be permitted unless the wound is frankly pussy In that event a daily slow drip of 500 mg in 1 000 ml of normal saline may be used for several days by way of a fine catheter which should be pulled out of the wound after completion of the daily drip. Practically all of these wounds will heal by delayed closure in several weeks

In all of these circumstances compression bandages should be continuously applied and reapplied.

Plaster of Paris support is rarely used. In the exceptional case it should be utilized to prevent the occurrence of a fracture and in the presence of a pseudoarthrosis or a nonunion. In these cases the compression bandage is modified to include plaster of Paris re-enforcement until healing of the wound has occurred, and thereafter skin fitting plaster of Paris bandages are applied.

Weight bearing as a rule is avoided for three months after the operative intervention in all osteomyelitic lesions with the exception of those of the upper extremities. Occasionally additional protection against postoperative fracture may be advisable. This can be afforded by the use of braces or plaster of Paris bandages.

A word should be added regarding the modification of the operative procedure in the event of lack of adequate skin coverage due either to long-standing ulceration or to the presence of thin adherent, atrophic skin such as one sees with sufficient frequency in long-standing osteomyelitis of the tibia. In these instances, the unsatisfactory skin edges should be excised and, at the termination of the saucerization procedure the skin edges should be undermined for a distance of three to four inches if necessary to permit primary closure. If this should prove inadequate releasing incisions may be made to permit primary closure over the saucerized area. The resulting gaps may be covered with split-thickness grafts. Many of these cases will result in primary healing Some will undoubtedly fail, because of embarassed circulation of the skin edges. The latter type will require additional skin grafting or skin plastic procedures before healing takes place.

Another word should be added regarding the modification of saucerization and primary closure under antibiotic control by the use of bone grafts—spongy or cortical autogenous or homogenous—either in an effort to fill a large bone cavity or in the presence of a pseudoarthrosis or nonunion complicating the osteomyelitic lesion I have avoided the use of bone grafts to fill large bone cavities because I have found it unnecessary There is practically always sufficient bone regeneration to permit weight bearing at the end of three to four months. Furthermore the use of bone grafts, admittedly foreign bodies, in the presence of infection is an unwarranted risk and involves an unwarranted dependence upon antibiotics It is preferable in the care of the first group and in all of the second group to obtain pri

mary healing and at a later date if necessary do a bone grafting procedure, under antibiotic control in the absence of infection.

End Results Time will not permit nor is it intended to enter on this occasion into a discussion of end results. This mode of treatment has already been evaluated statistically after an experience of five years, and the findings, which were most satisfactory were reported elsewhere.[4] Another study is under way to evaluate statistically all of my experiences with this regimen since its inception in 1944 and will, I hope be appropriately reported. Suffice it to say for the present that the results have been most pleasing to both the patient and the surgeon and at times even spectacular under most difficult circumstances with respect to the extent of the lesion in question and its length of time in existence.

SUMMARY

The above presentation is an outgrowth of a series of studies by myself and my associates at the Hospital for Joint Diseases, covering a period of some thirty years, and is a recapitulation of personal experiences and a progressively developing philosophy concerning treatment of the osteomyelitic lesion in all of its phases. These have been reported from time to time. This presentation is aimed toward a better understanding of the anatomical, physiological, pathological, and bacteriological considerations underlying the clinical course and the rationale of therapy of the osteomyelitic lesion.

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ELECTROMYOGRAPHY—ITS APPLICATION IN ORTHOPAEDIC SURGERY

Electromyography is an expression of neuromuscular activity in terms of peripheral motor behavior To appreciate the electromyograph one should be aware of basic neuroanatomy and the composition of the *motor unit*.

When one studies muscular behavior such as the pattern of phasic activity one is actually examining central nervous system behavior patterns through observation of peripheral neuromuscular activity The motor unit represents the motor terminal of the central nervous system and its behavior is an expression of complex pathways.

ELECTROPHYSIOLOGICAL BASIS OF THE ELECTROMYOGRAM

Normal electromyograms are diphasic type waves made possible by changes in potential along the membranes of muscle fibers. This change of potential closely coincides with the process of innervation Muscular contraction is thought to follow the potential change very closely—within a matter of two or three milliseconds. Each grossly diphasic wave as observed on the recording medium is thought to represent the firing of one motor unit. The motor unit behaves according to the all-or-none law The steplike rise in tension as the strength of a muscular contraction increases indicates that the all-or none law applies to the motor unit

This type of innervation is in contrast to that of the cardiac muscle which is innervated by a syncytium. Normally the entire ventricular mass of cardiac muscle behaves as a unit according to the all-or-none law The wave of excitation spreads from fiber to fiber This also produces a diphasic type of oscillation, variations of which indicate certain types of pathology which have been established to a certain *extent by empiricism.*

The motor unit has been defined as the group of fibers innervated by a single axone. As such, each motor unit represents a single anterior horn cell. The resulting diphasic wave during contraction varies in the normal because of slight asynchrony of fibers within the motor unit. Recruitment can thus be interpreted as the excitation by the central nervous system of additional motor units to take part in the activity Actually the innervation of the motor unit has been found to be less simple Overlapping of motor units by axones has been reported.[7] Each motor unit in the human anterior tibial muscle is thought to contain approximately 600 fibers and to have a diameter of about 1.5 mm.[21] The axone innervating this motor unit, however may also give off branches to a few other fibers. Identical action potentials have been obtained from a single fiber by stimulating separate axones. The innervation of the motor unit is thus not confined entirely to one axone.

As the axone penetrates the motor unit it branches to supply many fibers. It has been shown that in certain animals, such as the hamster there are more muscle fibers than motor end plates. In some of the skeletal muscles of the hamster there are three times as many fibers as axones

The fibrillary potential has a much shorter dura

tion and a lower amplitude than that of the normal motor unit. It can be recorded from denervated muscle fourteen to twenty-one days after interruption of the peripheral nerve. It has a characteristic appearance on recording media as well as a high frequency clicking sound in the loud speaker. It is a very useful diagnostic sign. In the primary myopathies no fibrillary potentials are ordinarily found. In amyotrophic lateral sclerosis or acute poliomyelitis one would expect to find these potentials. They indicate involuntary contractions of single denervated muscle fibers.

Fasciculation, on the other hand, represents an isolated contraction of the entire motor unit. This phenomenon, too, is characteristically found in amyotrophic lateral sclerosis.

TYPES OF ELECTRODES

Surface electrodes may be easily applied, using electrode jelly. This type of applicator is excellent for large muscles or groups of muscles but lacks the specificity of other types of electrodes as described below.

With the coaxial electrode (Fig. 198) one can make recordings from single motor units, and thus

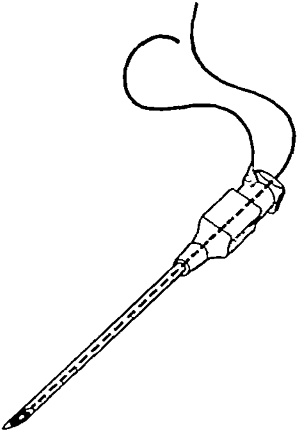

Fig. 198. The coaxial electrode.

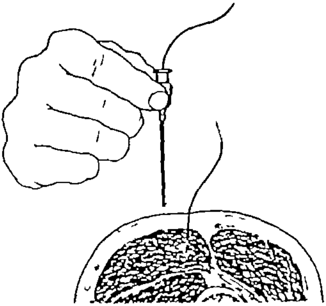

Fig. 199. Dual electrodes.

is the type of applicator most often used to study the pathology of the motor unit and to record fibrillary potentials.

Studies of single motor units and even of individual fibers can also be made while using a single monopolar electrode with ground.

Dual internal electrodes (Fig. 199) have many advantages. They transmit a large signal that does not require high amplification. This results in minimal distortion and interference. There is a very low noise level because of the large signal. The electrodes are specific and permit stimulation of the muscle for purposes of identification. This is very important in orthopaedic functional studies where the observer wishes to record individual muscle action. Such electrodes are painless and remain in place for long periods. Although they do not sample the entire muscle, they sample a large volume of muscle—enough to represent the muscle's activity. These electrodes are made from flexible, insulated, fine copper wires and are inserted with No. 22, 23 or 24 hypodermic needles. With the electrodes in place (Fig. 200) the subject may be observed during walking or other activities. The signal produced is ideal for recording on the sound track of the sound motion picture camera. This results automatically in a synchronized display of muscular activity and the accompanying audio representation of the electromyogram.

The magnitude of the signal obtained varies with several conditions: (1) type of electrode (Figs. 198 and 199), (2) size of exposed tip of electrode, (3)

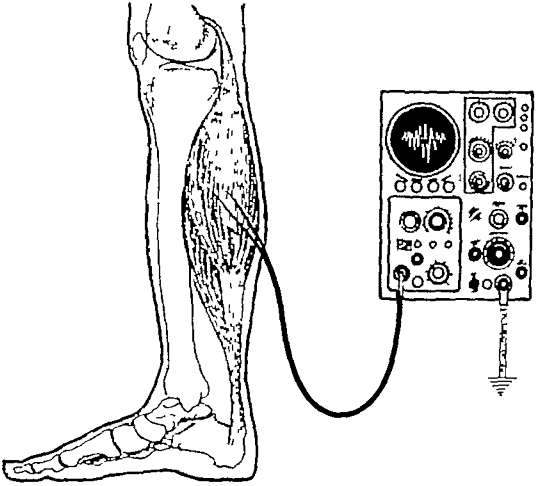

Fig. 200. Apparatus with dual electrodes in place.

distance between electrodes, (4) choice of muscle—upper extremity lower extremity etc., and (5) pathological state of the muscle. For example in primary myopathy the signal is small, while in anterior horn cell disease such as poliomyelitis the signal is of higher amplitude.

The coaxial electrode is highly selective and can be depended upon to display small portions of the muscle such as the individual motor unit. It is also capable of reproducing the insertion potential, which is helpful in some diagnostic considerations. Dual electrodes sampling several motor units simultaneously usually fail to record the shape of individual motor unit potentials since these—to a great extent are superimposed as groups (Fig 201) For purposes of locomotion studies and muscle action analysis, these flexible wire electrodes are usually placed 2 cm apart (Fig 200)

RECORDING EQUIPMENT

Many types of instruments are used for recording the action potential Some of the main requirements are suitable frequency-recording range and low noise level. The cables from the electrodes to the recording apparatus should be well shielded and the apparatus should be well grounded. A frequency-recording range of 50 to 10 000 cycles per second is desirable for most studies. Ink writers, although capable of recording several muscles simultaneously through a number of channels, have a low upper frequency limit and are, therefore incapable of recording fibrillary potentials. Thus they might be useful for muscle function studies but unsatisfactory for neurological studies or studies of the individual motor unit. Oscillographs employing the galvanometer have a greater frequency range but their upper frequency limit is usually something less than 5 000 cycles per second. With oscillographic equipment, several channels may also be available The ideal equipment for display of the electromyograph signal is the oscilloscope. With this instrument, the signal can be visualized and analyzed on the oscilloscope screen before or during recording Such equipment has controls which may be varied. Thus one

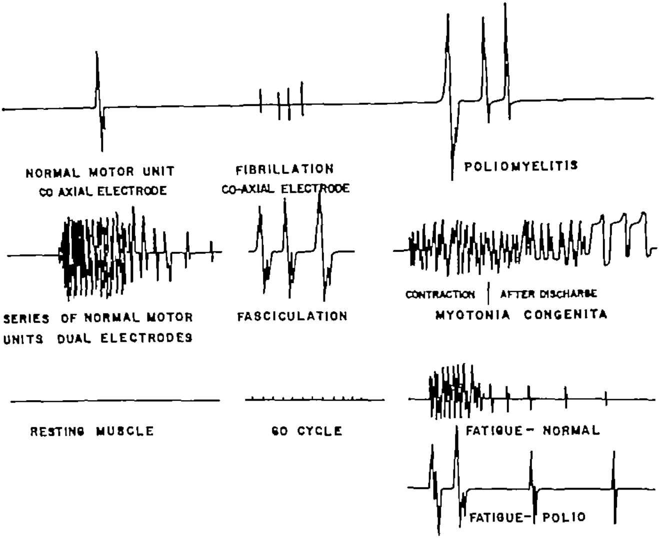

Fig 201 Some typical electromyographic records.

can make records at different frequency ranges (Fig 202) The instrument can be calibrated and one can appreciate the magnitude of the signal recorded. The oscillation may be swept across the screen for analysis by the horizontal (sweep) amplifier or the horizontal dimension may be introduced by continuous recording equipment such as the 35 mm. Fairchild camera. Three-channel oscilloscopic instruments such as the Disa are available. These instruments have a very satisfactory frequency recording range. The standard oscilloscope however can be adapted for multichannel use by the adoption of a rapid-switching device which switches the electron beam very rapidly from one input channel to another This requires the use of additional amplifiers.

With many of these devices the signal can be integrated. This means that a summation curve can be made of both the positive and the negative values, thus transforming the record into a continuous graph. Most integrators which rectify the signal, however depend upon condensers and therefore introduce some "lag" into the recording [14]

The loud speaker may also be used to demonstrate the signal. The audio representation is valuable and can be conveniently used while the electromyogram is being recorded, as another means of monitoring the phenomenon. The audio signal can also be recorded by tape recorders or on the sound track of motion picture film. The latter results in a self synchronized recording of the subject's activity and the electromyogram in audio-visual form.

There are artifacts which produce confusion in interpretation of the electromyogram. Some of these are 60-cycle (or alternating) current, diathermy excessively high recording frequencies with the introduction of radio frequencies, and excessive ampli

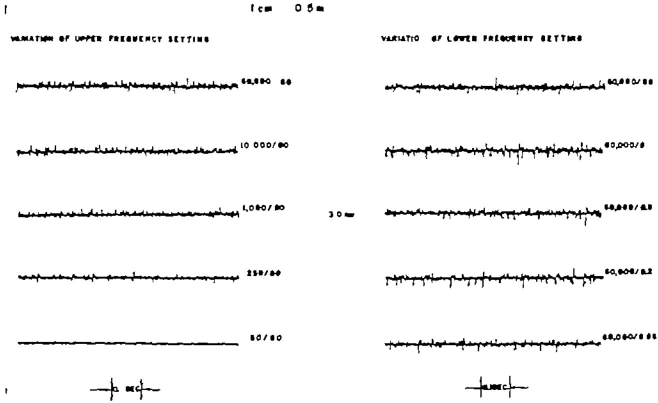

Fig. 202. Effect of variation of frequency recording range on oscillogram of vastus medialis during extension of knee.

fication. Some of the better oscilloscopes have high signal to-noise ratios which minimize the recording of artifacts.

APPLICATIONS OF ELECTROMYOGRAPHY IN ORTHOPAEDIC SURGERY

While one does not depend upon the electromyogram to make the diagnosis in itself it is often a valuable adjunct to a neurological study Sensitive equipment readily records the fibrillation potential, thus enabling one to appreciate peripheral nerve injury such as damage to the radial nerve in fractures of the shaft of the humerus. The decision to explore the radial nerve may depend upon the findings gained from the electromyographic test.

In distinguishing primary myopathy from a myopathy secondary to nervous system pathology it is easy to value the fact that primary myopathy does not produce fibrillary potentials, so characteristic of the muscle with a lower motor neuron lesion at certain stages Since our clinical and pathological descriptions of some muscular and neuromuscular entities overlap and are somewhat vague as to boundaries, the value of the electromyogram may be appreciated when it is pathognomonic, as in myotonia congenita. Here the electromyogram produces a characteristic sound in the loud speaker and may be the most definite means by which a conclusive diagnosis can be made. The characteristic "dive bomber" sound of myotonia congenita* gives the disease picture definite meaning that one is not likely to forget. The primary myopathies thus may be contrasted with diseases due to nervous system lesions, such as progressive muscular atrophy amyotrophic lateral sclerosis, myotonia congenita, and syringomyelia

In chronic poliomyelitis, motor unit recordings are characteristically of longer duration and higher amplitude. The phenomenon of synchronization has been pointed out by Hertz and co-workers.[8] This *is a finding of identical electrical behavior* in various parts of involved muscle presumably a result of fusion of anterior horn cell activity due to disease.

In 1941 to 1944 Schwartz and associates[22, 23] demonstrated by electromyographic means evidence of spasm in acute poliomyelitis. Early spasm was observed in the antagonist as well as the protagonist.

* This may also be heard in dermatomyositis.[7]

This spasm at times exceeded voluntary muscular contraction. During this stage of the disease marked electrical activity was observed on stretch. Spasm was often observed in *apparently unaffected muscles*, but here the electrical activity of voluntary contraction exceeded that of spasm. There was no spasm if voluntary contraction was *impossible*, and *spasticity* was considered a generalized phenomenon in early polio. No correlation was observed between initial spasm and residual weakness. The "spine sign" may thus be a reflex of uninvolved muscles in polio. Muscle, of course, is incapable of spasm unless the lower motor neuron is preserved.

The electromyographic method has been useful in establishing the level of cord lesions in such conditions as cervical or lumbar herniated intervertebral discs. The test is of particular value if myelography fails to localize the lesion. In disc lesions posterior muscles innervated by posterior primary rami may demonstrate electromyographic evidence of root compression. If one is considering a diagnosis of herniated cervical intervertebral disc or brachial plexus injury the differentiation can often be established electrically on the basis of involvement of posterior musculature which is innervated by posterior primary rami. In plexus lesions, these muscles are spared and produce normal action potentials. This is also true of lumbar disc lesions, where root compression is very unlikely if one cannot demonstrate evidence of fibrillary potentials in the posterior musculature of the lumbar spine.

Extensive use has been made of the electromyogram, using multichannel equipment during cortical *stimulation in* order to gain further appreciation of the extent of cortical representation.[8]

One of the most profitable applications of the method is in the study of locomotion. With the use of flexible internal dual electrodes the activity of various muscles including the deep muscles of the lower extremity the hip and also the iliopsoas muscle, can be recorded as the subject walks or performs other acts. Where a *tendon transfer has* been made, muscles are readily evaluated postoperatively. The time of contraction and, to a certain extent the magnitude of *electrical activity* can be appreciated. Preoperative study of the muscle to be transferred may be of great value. Using the instrument postoperatively *one may readily* ascertain the degree of recovery of the muscle and thus decide when sufficient training has been given. This can be appraised best *if a preoperative* study has been done.

Traditional methods of determining muscle function are (1) by study of the origin and insertion of the muscle (2) by observation of the effect of electrical stimulation, and (3) by observation of paralytics in whom certain muscles are paralyzed or weakened.

A *more* satisfactory study might be based on observation of actual participation of the muscle during specific movements. This is possible with the use *of electromyographic equipment. Records of electrical* stimulation, voluntary contraction, and the use of the muscle during normal walking are easily obtained. Considerable insight into the *function of* muscles can be gained by using this information along with a knowledge of the axes of the joints of the lower extremity about which these muscles act.[9]

The well known axis of the subtalar joint, as an illustration which enters the lateral aspect of the tuber of the os calcis and emerges from the dorsal aspect of the head of the talus, passes through the center of the spherical portion of the head of the talus. This axis (Fig 203) to a great extent influences the action of the anterior tibial, peroneal, posterior tibial, and common extensor muscles (Figs. 204 to 207) When tendon substitutions are made about such axes, the position of the axis and the time of contraction of the muscle are important considerations (Figs. 208 and 209) For example, with paralysis of the anterior tibial muscle, one may wish to transfer the common extensor into the dorsum of the foot. The surgeon must then determine the ideal position for insertion of the trans

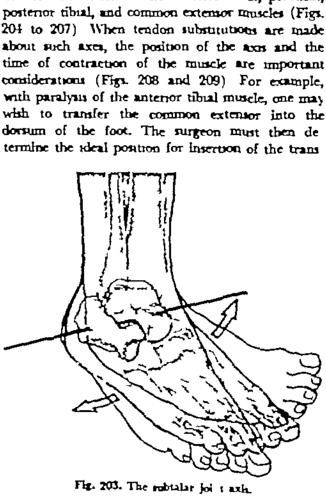

Fig. 203. The subtalar joint axis.

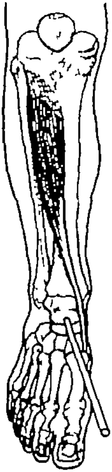

Fig. 204. Course of the tibialis anticus with respect to the subtalar axis.

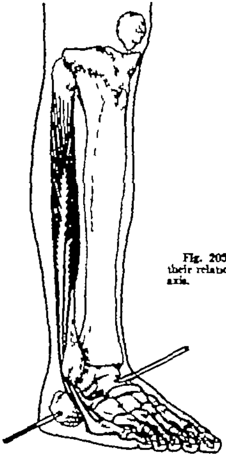

Fig. 205. The peroneals their relation to the subtalar axis.

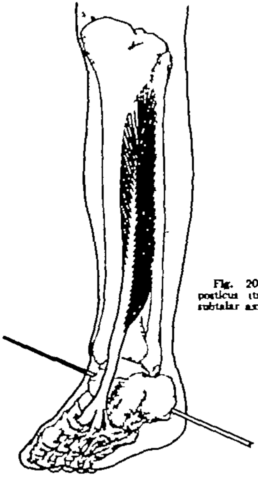

Fig. 206. The tibialis posticus its relation to the subtalar axis.

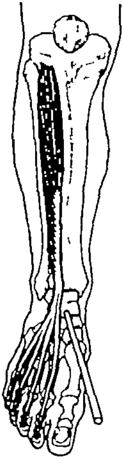

Fig. 207 Relationship of the common extensor to the subtalar axis

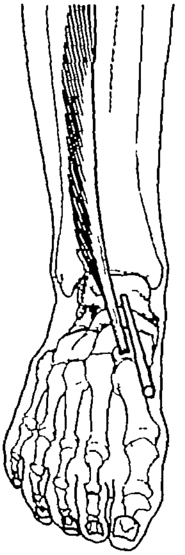

Fig. 208. Consideration of the subtalar axis in transfer of the common extensor into the dorsum of the foot.

ferred tendon with respect to the axis of the subtalar joint. (Figs. 208 and 210.)

In order to appreciate the action of muscles of the lower extremity such as the adductors one must consider the mechanical axis of the lower extremity (Fig 211) This axis influences the action of both the adductor longus and the adductor magnus, determining their participation in horizontal rotation of the thigh. The principal distal attachment of the adductors into the posterior aspect or linea aspera of the femur suggests that they are external rotators. Their attachment however is more important in relationship to the mechanical axis of the lower extremity (Figs. 212 and 213) The axis of the lower extremity is undoubtedly a line passing from the center of the head of the femur to the point of contact of the lower extremity If the lower extremity is not in contact with the walking surface the mechanical axis passes through the head of the femur and the center of gravity of the dependent lower extremity The latter is, of course, a changing point and the axis therefore, is a constantly changing one (Fig 211) The action of the adductors is, therefore an especially complex consideration when the lower extremity is not in contact with the walking surface. After insertion of dual electrodes into either of these muscles one can easily stimulate and produce weak external rotation and adduction. Upon observing the electromyographic recording however one is impressed by the muscles lack of activity on external rotation and their abundant activity on internal rotation or adduction. This paradoxical finding indicates the futility of attempting to determine the action of muscles by means of their response to electrical stimulation. Undoubtedly the body uses muscles as groups and some cannot even be used individually According to Duchenne, "a single muscle has no function as such." According to Jackson,[18] "the brain knows nothing of muscle, only of movement." Thus, motions and not muscles apparently are represented in the brain.

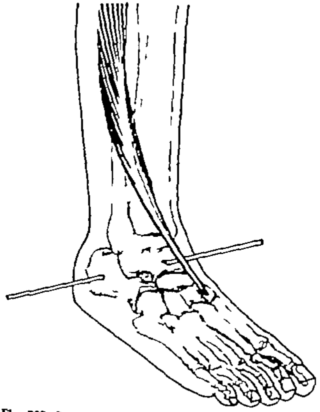

Fig 209. Peroneal transfer to the dorsum of the foot and the position of the subtalar axis.

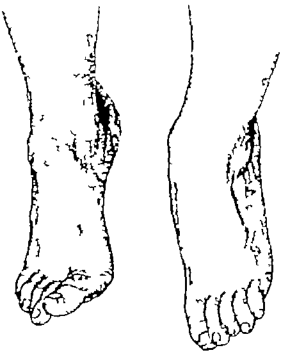

Fig. 210. Dorsiflexion—in the presence of tibialis anticus paralysis.

Studies of the normal hamstrings reveal further interesting findings. The short head of the biceps femoris by stimulation or voluntary contraction is a consistent flexor of the knee. The long head, however in many individuals is inactive on knee flexion but very active on extension of the thigh or external rotation of the lower extremity These muscles do not contribute substantially during normal walking, *according to findings by the electromyogram.*

Another demonstration of the importance of mechanical axes and centers of rotation in the analysis of muscular function is seen in the activity of the iliopsoas muscle (Fig 214) As this muscle passes downward to the lesser trochanter of the femur it passes directly over the head of the femur There has been disagreement concerning the role of this muscle in internal or external rotation of the lower extremity In order to study the functions of the components of this group, electrodes were placed in the iliacus muscle, as well as in the psoas muscle via a posterior route. Electrical stimulation invariably produced pure flexion without internal or external rotation. The electromyogram revealed no activity on internal rotation but slight activity on external rotation of the thigh. There was abundant *activity on flexion of the thigh and, surprisingly* abduction. As demonstrated by Fig 215 when the hip is abducted a portion of the tendon of this muscle passes lateral to the head of the femur the muscle then becoming an abductor During walking the iliopsoas muscle is relatively quiet. It is used only during the first step or while the subject ascends stairs, when it shows abundant activity

The instrument would be much more valuable as an orthopaedic study device if the electromyogram could be directly related to the tension produced by the muscle. The amplitude of the signal may vary somewhat from day to day with each insertion of the electrodes into a given muscle. During a specific test, however it has been observed in other studies that the integrated electromyogram has a linear relationship to the developed tension of the muscle, if the contraction remains isometric.[14, 19]

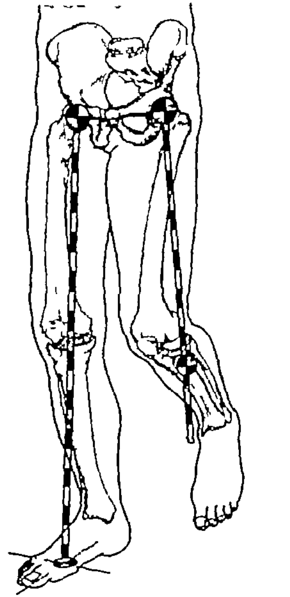

Fig. 211. Mechanical axes of the lower extremity

axones to motor units. Each motor unit thus consists of a much smaller number of muscle fibers. It has been found that the extraocular muscle is never at rest. Some electrical activity can always be elicited, even during sleep. The procedure has been carried out with flexible internal electrodes, using only sedation and local anesthesia.

In determining the state of innervation of muscle one can often observe partial denervation. The state of regeneration can be observed. For example, fibrillary potentials are usually first observed in the denervated muscle fourteen to twenty-one days after nerve injury. If denervation is complete, fibrillary potentials gradually disappear as the fibers themselves degenerate. The electromyograph thus records the progressive changes in wallerian degeneration. If denervation is incomplete and regeneration follows, fibrillary potentials may gradually transform into a series of units, small in amplitude and duration and out of phase (the nascent motor unit) [11, 2]. These potentials finally resolve themselves into the diphasic form of the normal motor unit.

Clinically it is often difficult to differentiate certain myopathies and atrophies of central origin. In primary diseases of muscle without known nervous system involvement fibrillary potentials are almost never observed. An example of such myopathy is pseudohypertrophic muscular dystrophy without any known nerve lesion and without fibrillary potentials but with a family history of disease and disturbance of creatin-creatinine metabolism. Central atrophies on the other hand usually begin

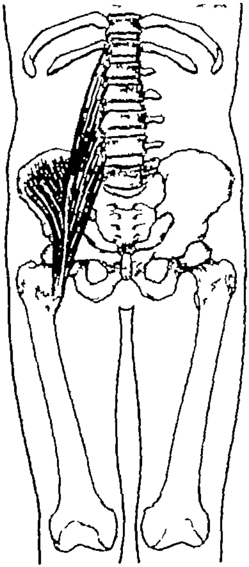

Fig. 214 The iliopsoas muscle

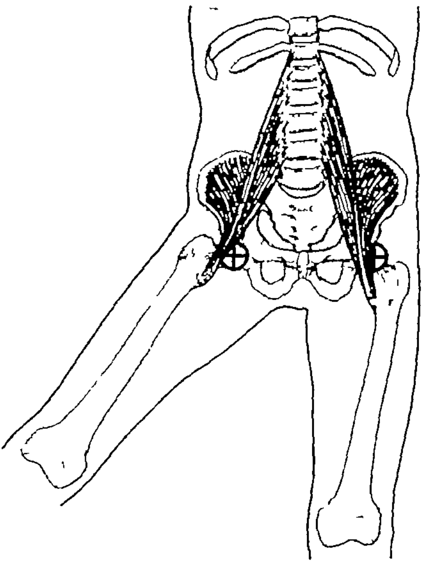

Fig 215. The iliopsoas muscle in abduction.

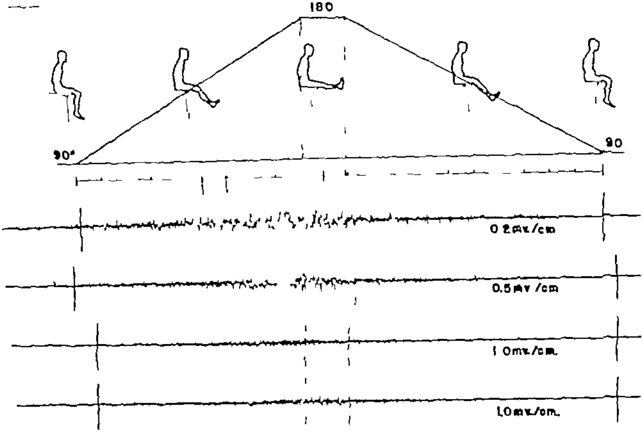

Fig 216. Action potentials of the vastus lateralis on knee extension. Progressive decrease of oscilloscope sensitivity

in the middle or latter parts of life. The distal portions of the extremities are often first involved. An example of this type of involvement is the Charcot Marie-Tooth syndrome (although this disease generally occurs early in life) [1] Here fibrillary potentials are usually found. Spasticity is often observed, in contrast to the primary myopathies, where it is absent. Examples of central atrophies are progressive muscular atrophy amyotrophic lateral sclerosis, and myotonia congenita. Peroneal muscular atrophy is another example of central atrophy where there is involvement of peripheral nerves posterior columns, or pyramidal tracts. Muscular involvement is secondary and there are usually fibrillary potentials.

In the study of normal muscle function, individual muscle action has been demonstrated during various activities However such action or function should be thought of as participation in a group activity in which a number of synergists take part. Thus no claim can be made for individual, isolated muscle function. Single-channel equipment has been used in this study since the electromyogram is recorded on the sound track of the motion picture film. T however gives an excellent self-synchronized play of both the movement and the muscle's e trical activity One can very readily appreciate individual participation of each muscle in cer activities. Multichannel equipment undoubtedly many great advantages in the study of mu function, as the tracings of several muscles ma simultaneously recorded. Since each muscle requ a pair of internal electrodes for this type of st it is possible that normal movement may be so what inhibited by the use of too many inte electrodes at one test.

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In determining the state of innervation of muscle one can often observe partial denervation. The state of regeneration can be observed. For example, fibrillary potentials are usually first observed in the denervated muscle fourteen to twenty-one days after nerve injury If denervation is complete, fibrillary potentials gradually disappear as the fibers themselves degenerate The electromyograph thus records the progressive changes in wallerian degeneration. If denervation is incomplete and regeneration follows, fibrillary potentials may gradually transform into a series of units, small in amplitude and duration and out of phase (the nascent motor unit) [13, 14] These potentials finally resolve themselves into the diphasic form of the normal motor unit.

Clinically it is often difficult to differentiate certain myopathies and atrophies of central origin. In primary diseases of muscle without known nervous system involvement fibrillary potentials are almost never observed. An example of such myopathy is pseudohypertrophic muscular dystrophy without any known nerve lesion and without fibrillary potentials but with a family history of disease and disturbance of creatin-creatinine metabolism. Central atrophies on the other hand usually begin

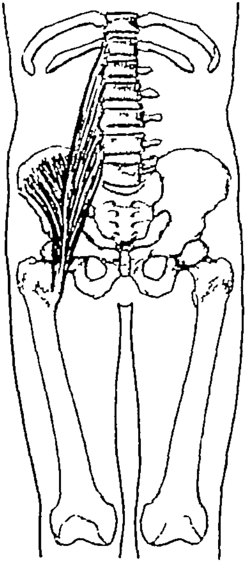

Fig. 214 The iliopsoas muscle

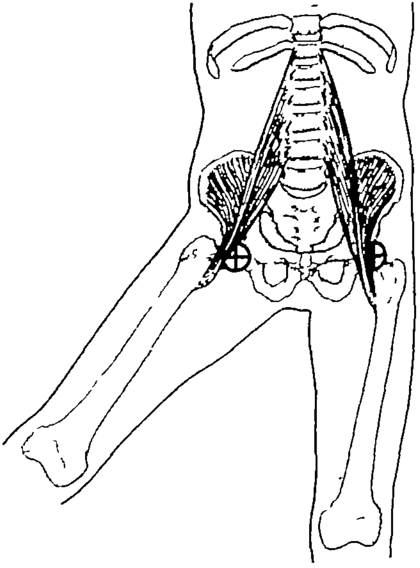

Fig. 215. The iliopsoas muscle in abduction.

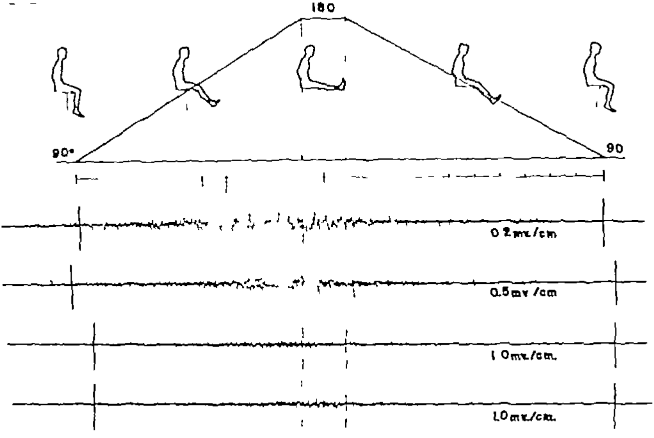

Fig. 216. Action potentials of th[e v]astus lateralis on knee extension. Progressive decrease of oscilloscope sensit[ivi]ty

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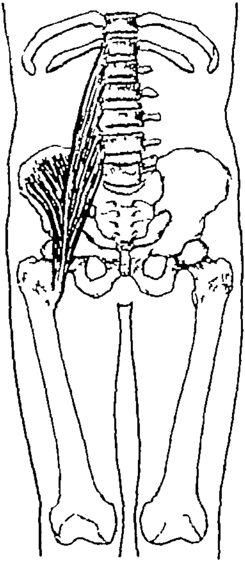
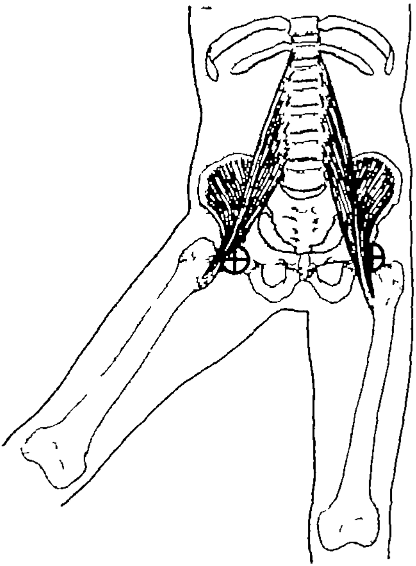


Fig. 214. The iliopsoas muscle.



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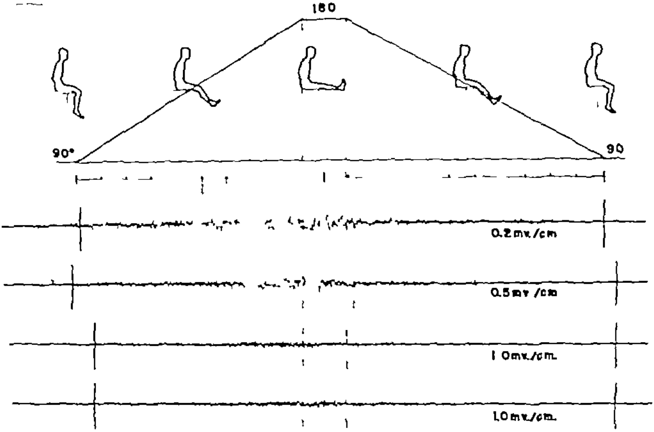

Fig. 216. Action potentials of the vastus lateralis on knee extension. Progressive decrease of oscilloscope sensitivity.

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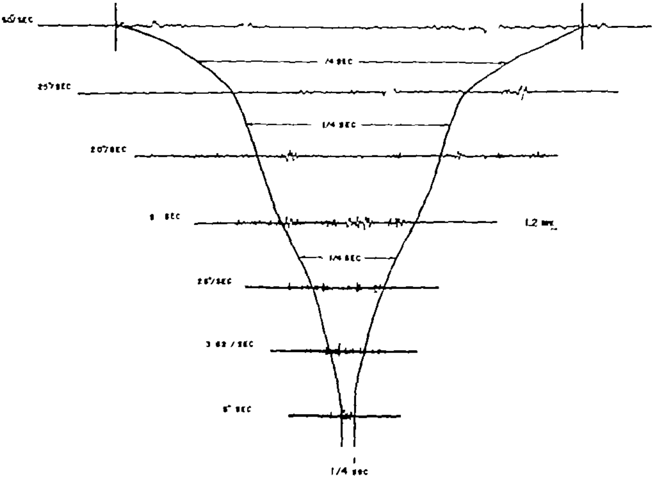

Fig. 217 Oscillograms, made at various recording speeds, from normal gastrocnemius during walking

or base line is introduced. As the impulse is swept across the screen, however part of the activity is not seen or recorded, since each sweep must end and then be resumed on the other side of the oscilloscope screen. When using continuous recording equipment only the vertical oscillation is displayed. The sweep or time dimension is supplied by constantly moving recording material. In this case 35 mm photographic paper or film is used. Since the rate of the recording material can be varied, one can easily run the Fairchild camera at the same rate as the sound motion picture camera. This produces a conveniently synchronized system which records all of the electrical activity taking place without interruption. Th events taking place during the subject's activity such as walking with the proper designation of stance phase swing phase etc or of voluntary contraction, such as extension of the knee can then very easily be transferred to the 35 mm. paper. The electrical activity can thus be appreciated in relationship to what the patient is doing as demonstrated in Figs. 218 and 219 In this way phasic activity during walking may be precisely recorded. Although the action potential may vary from day to day for a given muscle, certain standardization is made possible by the use of this particular equipment. Thus a gain of approximately 20,000 is used for each test. The oscilloscope sensitivity may be set at the same setting of 0.5 mv. per centimeter—a setting which can almost always be depended upon to record normal musculature in the lower extremity. The speed of the recording system remains constant, avoiding the introduction of unfamiliar forms of the action potential. The effect of varying the recording speed is shown in Fig 217

Several dynamic and structural changes are known to occur in muscle as contraction takes place. These include changes in (1) length, (2) cross section, (3) viscosity and (4) tension

When contracting muscle shortens, as during isotonic contraction, the maximal rate of change

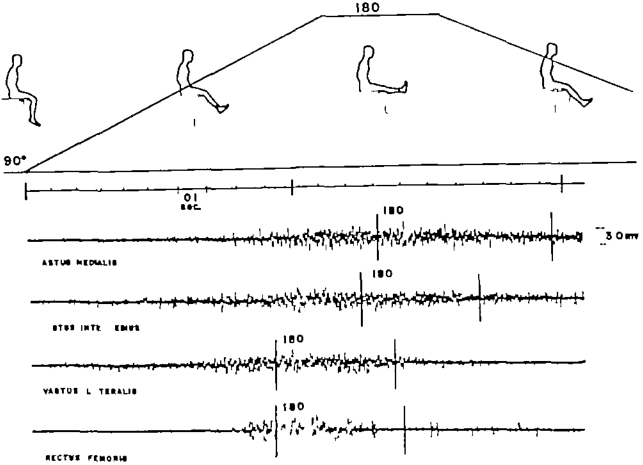

Fig 218. Participation of the quadriceps components during extension of the knee.

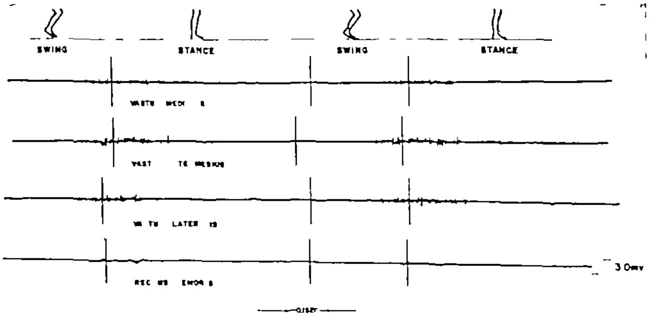

Fig 219 Phasic activity of the components of the quadriceps muscle

is proportional to the length of the muscle i.e., velocity of shortening is proportional to muscle length.[29] The maximum developed tension is proportional to the muscle's cross section. During isometric contraction the pattern of the integrated electromyogram can be shown to be proportional to the developed tension. However if isotonic contraction takes place at a constant rate the integrated electromyogram can also be shown to be proportional to the developed tension

Chemical changes involving adenosine triphosphate "actomyosin" pH etc. result in the giving off of heat. Electrical changes occur along the membrane This electrical change whether due to the metabolism of "actomyosin" or to differential permeability of the membrane, can be shown to be coincident with the action potential. The action potential is almost coincident with the development of tension the latent period being approximately 0.002 second. The action potential, however terminates prior to the cessation of muscular contraction.

The amplitude of the action potential thus depends upon several factors. It varies with the type of electrodes used and the adjustments of the oscilloscope. It also varies according to the distance between electrodes placed in the muscle. The action potential produced represents the activity of the number of motor units in the immediate area surrounding the two electrodes. Often individual motor unit discharges cannot be seen with this type of recording device since vigorous muscle activity produces abundant electrical activity that results in superimposition of many motor units, one upon the other and loss of identity of the individual motor unit The electrical content of the area examined, however is represented by the recording

Electromyographic analysis of the phasic activity of normal hamstring muscles and quadriceps components has been very useful in the analysis of hamstring replacement transfers to the patella for quadriceps weakness The familiar picture of persistent hip and knee flexion contracture with weakness of the quadriceps, the patient attempting to advance th center of gravity of the body anterior to the mechanical axis of the knee can be changed dramatically by forward transfer of hamstrings in some cases The hip flexion contracture and lordosis may be a necessary result of the knee flexion contracture especially if the gluteus maximus and gastrocnemius muscles are weak since the patient must place the center of gravity in front of the knee axis to prevent collapse. Here plaster wedging of the knee alone is not necessarily permanent and may have to be followed by measures to balance the muscle distribution about the joint—in this case, hamstring transfer to the patella Hamstring transfer may succeed dramatically in maintaining the correction, eliminating the necessity for the flexed position of the hip and for the lordosis. One of the hamstring muscles may be found preoperatively to have a considerable amount of stance phase activity Such a muscle might be a very desirable one to use However continuing swing phase activity of some hamstring transfers may also be useful in extending the knee joint prior to the onset of the stance phase. In some cases, the transfer actually produces extension throughout swing thus resulting in the "stiff legged" gait.

Fig 219 demonstrates the individual phasic activity of the quadriceps components. It is observed that their amplitudes are low and the duration of contraction short. Contraction begins normally in the quadriceps components just prior to the onset of the stance phase Activity is concluded just prior to the mid portion of the stance phase. In all of the records in this study the factors of recording speed, oscilloscope sensitivity and gain are the same Using this standard procedure one consistently observes that during normal walking the rectus femoris plays a smaller part than the other quadriceps components. Hamstring transfers are frequently made because of marked instability with bilateral quadriceps paralysis or because of external rotation of the tibia with genu valgum in the presence of a strong outer hamstring Occasionally the hamstring transfer into the patella succeeds in duplicating the quadriceps stance phase" activity during normal walking In other cases, the muscle retains its swing phase activity during level walking but may spontaneously change to the stance phase as the subject ascends stairs.

The hamstring muscle transferred to the patella may be disappointing in its failure to produce complete knee extension in the absence of a quadriceps mechanism One wonders if it is possible for a single muscle such as the semimembranosus or the long head of the biceps femoris, to produce complete extension and a full range of motion of the knee Such a transfer has actually been substituted for a complete group or system of muscles of varied lengths. In our experience complete extension is possible if one sacrifices some flexion in such transfers as the b s to the patella However

if stretching of the transfer is permitted and complete flexion produced extension invariably suffers Thus the transfer though capable of producing complete extension is not capable of duplicating the action of the normal quadriceps mechanism to the extent of producing a complete range of motion. This leads to a study of the activity of the various components of the quadriceps mechanism during extension of the knee (Fig 218) One might postulate that different components of the quadriceps normally come into play at different stages as extension proceeds. In fact it has been suggested that the vastus medialis produces its activity at the terminal portion of extension in order to prevent lateral dislocation of the patella. Careful electromyographic recordings, however fail to substantiate this concept. Fig 218 demonstrates typical records obtained from the components of the quadriceps mechanism during voluntary extension of the knee. Although these records were made separately and not with multichannel equipment, they were repeated many times with consistent findings. It is clear that the three vasti begin their activity as extension is begun, their activity increasing in intensity as extension is completed. A difference is often observed in the activity of the rectus femoris. Although this is the longest of the four components, its activity normally begins later It often fails to participate in extension until the knee is almost completely extended to 180 degrees. Rectus femoris activity begins in most cases at a position of approximately 165 degrees. In this study (Fig 218) the contractions of the quadriceps components are isotonic until the knee reaches 180 degrees at which time the contractions become isometric.

SUMMARY AND CONCLUSIONS

The electromyogram has been employed for neurodiagnosis and the study of locomotion and muscle function.

In neurodiagnosis the test has become of great supplemental value in such conditions as cervical and lumbar disc lesions with nerve root compression, in brachial plexus injuries, and as an aid in the distinction between primary myopathies and those secondary to nervous system lesions. In neurological conditions the observation of the fibrillation potential is of great value Its presence may be observed two or three weeks after injury and followed as an excellent prognosticating sign.

In the study of locomotion, excellent records of muscle activity during walking both in normal and in postoperative orthopaedic reconstructive procedures may be produced This method is an excellent aid in the evaluation of the tendon transfer It is possible to penetrate with the electrodes deep muscles, such as the posterior tibial or the psoas major and record their activity when such activity might not be apparent by other means. Preoperatively the method may be of value in assessing the state and time of contraction of a muscle under consideration for transfer By adapting the apparatus to the sound camera, an appreciation of normal muscle function is readily obtained through production of a self synchronized audio-visual recording

Although much further development is taking place in the quality and adaptability of apparatus of this type much standardization has been possible, and its application has been extended to many branches of medicine.

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PART SEVEN

FRACTURES

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Danville, Pennsylvania

OPERATIVE TREATMENT OF FRACTURES OF THE ELBOW IN ADULTS

We should like first to pay tribute to the memory of Dr Robert A. Knight of Memphis, Tennessee who formerly presented this course on the management of fractures about the elbow in adults, which was published in Volume 14 of the Instructional Course Lectures.

Trauma in and about the elbow joint presents a real challenge to the physician who first encounters the problem, whether it be fracture fracture and dislocation, or severe injury to the soft tissues. The strong muscles which are attached to the various bony prominences comprising the elbow joint usually cause a marked displacement of the fragments of most fractures in this area. Thus there is very poor stability and manipulative or closed reduction of a displacement is difficult or perhaps impossible. To maintain conservative management of most of these injuries unless they are very simple in nature, such as linear fractures without displacement, usually gives a poor result. Therefore it behooves the surgeons responsible for the treatment of these injuries to approach them in a positive manner having a thorough knowledge of the anatomy both the early and the late complications, and a general knowledge of the management of the more difficult fractures.

The experience of many of the outstanding men in orthopaedic surgery has been recorded for the benefit of their confreres in this field, and we present a rather exhaustive bibliography of references within which these men have recorded their knowledge and experience

The discussion will be presented by individualizing the various types of fractures of the radius, the ulna, and the humerus, and followed with a review of some of the more complicated problems, including open fractures and dislocations, as well as complications encountered in the soft tissues.

A review of the surgical approaches or first hand information is perhaps one of the most important phases of surgery of the elbow joint. Because of the complicated types of fractures encountered, the incision must be properly placed or the operation will be very difficult, or even impossible, and subsequent incisions will have to be made. Some of the more commonly used and recommended surgical approaches have been described by Banks and Laufman, Bost and associates, Boyd, Boyes, Campbell Henry Kaplan, Molesworth, Pheasant, Speed and Van Gorder The early evaluation of a patient with an injury in and about the elbow should consist of a complete examination checking for possible nerve or vascular injury followed by adequate x ray study Too much emphasis cannot be placed upon the value of adequate roentgenograms. Several views may be necessary in order that the damage incurred may be properly evaluated prior to surgery and then the best surgical approach made

Surgical approaches (Boyd Bost and associates Henry) will be referred to as posterior approach (Speed, Molesworth) curvilinear posterior approach, lateral (Kaplan or Kocher) and medial approaches (Campbell) and anterior antecubital approach (Henry McLaughlin)

Re-emphasizing the importance of operative surgery in fractures in and about the elbow joint once the decision has been made for surgical intervention, we have found, almost without exception, sufficient damage within the joint and to the tissues surrounding the joint to indicate that nothing but a poor result would be achieved by nonsurgical treatment. Frequently one finds within the joint loose pieces of cartilage, blood clot and fragments of bone which would contribute to a poor result were they not removed at the time of the arthrotomy. It is our thesis that carefully planned and executed surgical operations performed under optimum conditions e.g. tourniquet, good light et cetera give us the best opportunity for a good functional result. We also feel that adequate fixation of the fractured fragments allows for early mobilization of the joint, which in turn prevents many of the poor functional elbows so frequently encountered after treatment by prolonged immobilization or fixation in one position with or without surgery.

Antibiotics are used in adequate amounts when indicated, but not routinely in the postsurgical period.

FRACTURES OF THE HEAD OF THE RADIUS

J. Albert Key divided these fractures into two classifications: those which should be treated conservatively (Fig. 220) and those that should be treated by operation (Fig. 221). From a surgeon's standpoint, this is certainly an excellent classification. However the fractures themselves vary considerably, frequently giving only mild symptoms consisting of some pain and limitation of pronation and supination but particularly acute pain on digital pressure laterally over the elbow joint. Roughly the fractures of the head of the radius may be classified as (1) linear single or multiple fractures, with or without displacement (2) segmental fractures, with or without displacement and (3) the comminuted fractures. In any of these classifications we should be cognizant of the fact that there may be some associated damage to the adjacent joint surfaces and that the fracture will occur occasionally with an associated injury in the distal wrist or distal forearm.

In the past few years there has been a tendency to operate on fewer radial head fractures, provided there is good pronation and supination in the presence of an acute injury. This is true of the first two classifications, and in most of these we have not regretted nonsurgical treatment. However relatively simple linear fractures with only a small fragment of the head displaced or impacted, where pronation and supination is limited, usually do not improve under observation. Such fractures may result in varying degrees of flexion deformity. If a conservative approach is planned, the distended joint should be aspirated after twenty four hours. Movement may be started early within the painless range usually only sling immobilization is used. The chisel type of fracture of the upper end of the radius is one in which there may be an impaction of the neck with little or no serious angulation of the head of the radius, and these fractures—unless there is definite involvement of pronation and supination—we treat conservatively as outlined.

In comminuted fractures of the head of the radius, in which there is usually more destruction and more displacement than is apparent on x ray examination operative treatment should be planned and accomplished. In general, we believe in operating early within the first twenty four or forty-eight hours, when indicated. If delay is unavoidable or the patient is seen late, operation may best be postponed up to four to six weeks. Two favorite operative approaches for the removal of the head of the radius are the lateral J-shaped incision of

Fig. 220. Simple compression fracture of radius, treated conservatively

Kocher and the lateral approach so aptly described by Bost and co-workers, through which the head and intracapsular portion of the neck of the radius are excised. The periosteum around the neck is removed. The bone is divided at the proper site by a sharp osteotome. A purse-string type of suture is used to close the synovium and joint capsule over the smooth proximal end of the radius. The remainder of the elbow joint is irrigated with warm saline solution and closed with interrupted fine chromic catgut sutures. It is imperative to check the head of the radius upon removal to be sure that *all* of the fragments are removed. Frequently a comminuted head of the radius may have fragments lodged in the torn anterior portion of the capsule or beyond the mid line of the joint anteriorly. In addition to this, the other joint surfaces should be thoroughly inspected and débrided if necessary. In recent years, we have placed 1 or 2 ml. of hydrocortisone into the joint on completion of surgery. Whether or not this contributes greatly to our improved operative result and to postoperative function is a hopeful thesis but possibly questionable. The wound edges are closed in layers and the forearm placed in a position of neutral pronation and supination and the elbow at a right angle. The patient may be out of bed the following day with his arm in a sling. Whether or not the splint is necessary for a period of three weeks so long as the arm is carried in a sling is problematical. We start active motion at the elbow after about three weeks. A physical therapist may guide the patient in his active motion but there is no substitute for the patient's own initiative and from postoperative follow up of all injured elbow patients it is our belief that the patient is his own best physical therapist.

There are certain complicated fractures of the elbow joint in which not only the head of the radius but possibly the coronoid process also is fractured. The antecubital approach or Z-type of incision as described and used so aptly by McLaughlin and Smith and others gives an excellent view for repair of the coronoid process, removal of the head of the radius, suturing of the torn capsule, débriding of the joint, et cetera. We believe this approach to be essential in this type of injury because of the extensive hematoma that develops at the injured portion of the brachialis muscle. Removal of the blood clot and repair of the fracture are important for the early restoration of function and minimize the possibility of myositis ossificans. The coronoid process if fractured may be small and may be sutured in position or if comminuted may be excised. The attachment of the brachialis muscle and coronoid process may be repaired by placing a pull-out wire suture through the loose fragment into a drill hole through the

A. B.

Fig. 221 A, Comminuted head of radius, treated by excision of head and neck. B, Six months postoperative view.

ulna, it being tied onto a button on the ulnar surface of the arm after the method of Bunnell. This is likewise the procedure that is used when the bicipital tendon has been pulled from its attachment.

Neck fractures of the radius are relatively rare, and in the adult are frequently oblique or spiral in nature. Attempts at treating these conservatively usually meet with failure and excision of the fragments as described should be carried out.

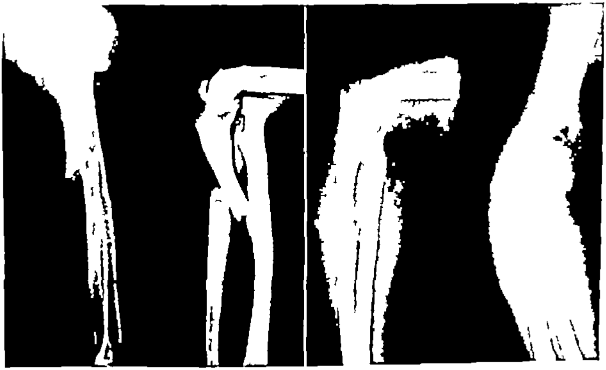
Peter Essex Lopresti has focused out attention on the possibility of an unusual relationship between the distal end of the ulna and the radius after a fracture of the head of the radius in some of the more severe indirect traumas. This must be borne in mind in fractures of the neck and severely comminuted fractures of the head of the radius.

FRACTURES OF THE ULNA

Fractures of the ulna may be divided into (1) those of the shaft, (2) Monteggia's fractures, and (3) fractures of the olecranon and the coronoid processes. The ulna, being close to the skin surface, is frequently involved in open fractures, particularly in sideswipe injuries, and these will be discussed later.

Fractures of the shaft of the ulna, involving the upper end of the shaft but distal to the joint, occur occasionally by a direct blow or by a direct fall on this portion of the forearm. They may be linear or comminuted and occasionally have moderate to severe displacement. If the fracture is simple the part is immobilized in plaster with the elbow at a right angle for a period of up to four weeks and is protected usually for a period of seven to eight weeks. The *comminuted* or severely displaced fracture may be treated by closed reduction successfully. However as in many single bone fractures, if this is not possible, open reduction and fixation are necessary. We prefer a long intramedullary rod in most ulnar shaft fractures, because of its ease of introduction, which gives firm fixation and allows for earlier mobilization.

Fracture of the proximal end of the ulna with a dislocation of the head of the radius, known as *Monteggia's fracture*, was first described in 1814 by the man for whom it was named (Fig. 222). There have been many excellent articles written concerning this particular injury and I particularly refer to that of Speed and Boyd. In this specific injury the head of the radius is most frequently dislocated anteriorly but occasionally will dislocate posteriorly or laterally. The ulna is most commonly fractured at the junction of the middle and the upper thirds, but it may be fractured in any portion of the shaft, and



A B

Fig. 222. A, Monteggia fracture illustrating the dislocated radial head. B, Illustrates six months end result of closed reduction, in flexion and supination. Excellent functional result.

particularly close to and involving the olecranon. On occasion this fracture may be treated by closed reduction and the head of the radius will return to its normal position and be held in this position by supination of the forearm with the elbow in flexion as described by Evans. The operator must be sure that motion of the elbow is adequate including normal pronation and supination, if this conservative approach is to be continued. When operation is necessary the ulna is openly reduced and immobilized by means of an intramedullary pin of one type or another. Recently we have preferred the Rush pin because it is somewhat easier to remove but a large Steinmann pin or other types of intramedullary pins may be used to immobilize the ulnar fragments. When this is accomplished it must be determined whether or not the head of the radius will remain in the joint and provide normal motion of the elbow. If this is not possible because of a prolapse of the capsular or annular ligament into the joint it is necessary to make a secondary incision to replace the head of the radius and suture the annular ligament and capsule. The antecubital incision particularly for the anteriorly dislocated head, is the approach of choice as this allows free access to the capsule and annular ligament for suturing after the head has been replaced or if the head has been fractured or badly comminuted the fragments may be easily removed. The blood clot may be removed and the injured brachialis muscle débrided thus eliminating some of the postoperative complications, such as excessive fibrous and calcification, or myositis ossificans which may result as a late complication.

When *malunion* or *nonunion* of the ulna is encountered in this injury the head of the radius generally having been dislocated for a long period of time it is usually impossible to repair the capsule and replace the head in its normal position. Therefore the head and neck of the radius should be excised and the ulna be realigned and fixed with an

A B.

Fig. 223. A, Monteggia type fracture one month following injury. B, Illustrates operative treatment: open reduction and fixation of ulna fracture with Steinmann pin and resection of the head of the radius.

intramedullary pin and when indicated, matchsticks of cancellous bone placed about the fracture site—which we feel hastens healing (Fig 223) When a more extensive repair is indicated an onlay graft of cortical bone fixed with screws not only gives stability but also helps to bridge the fracture site

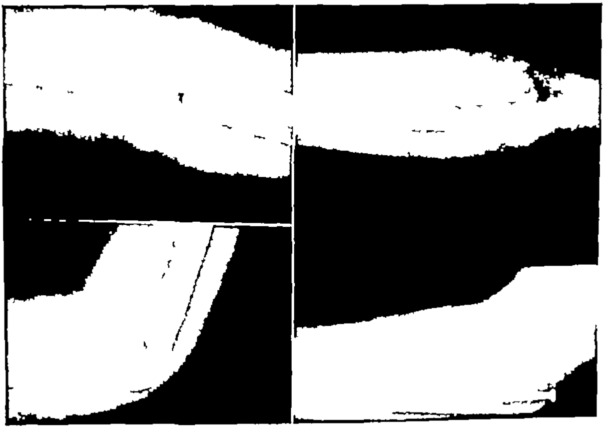
Fractures of the Olecranon

The most common fracture of the olecranon is the simple closed type, but occasionally severely comminuted closed and open fractures are seen. In the usual uncomplicated fracture with separation of the fragments, open reduction is performed through a posterolateral S type incision approximating the fragments, and a long intramedullary type of screw is used to immobilize the fragments. (Fig 224) The same result can be accomplished with a long intramedullary pin. The lacerated capsule and fascia are always sutured. With this fixation, early mobilization is possible, resulting in excellent function and end result. Immobilization may be safely established with the elbow splinted at a right angle. In a comminuted olecranon fracture the fragments may be approximated by a circumferential ligature or wire or possibly one or more screws. If the fragments are severely comminuted and it is impossible to reconstruct the normal articulating surface an excision of the fragments may be necessary the triceps ligament being attached to the fascia overlying the ulna. If this cannot be accomplished by the ordinary suture, a removable wire suture after the method of Bunnell, may produce the desired result. In open fractures of the olecranon it is felt that after thorough débridement of the wound, internal fixation of the fragments and closure of the wound is the treatment of choice.

Fracture of the coronoid process may or may not require open reduction, depending upon its size and the displacement and the type of injury Suturing of this process has been described under the discussion of fractures of the radius. These fractures are usually accompanied by associated injuries and particularly dislocation of the elbow

FRACTURES OF THE HUMERUS

Fractures of the lower humerus may be divided into (1) fractures of the lateral and medial epicondyles, (2) fractures of the capitellum and trochlea, (3)



A B.

Fig 224 A, Fracture of the olecranon B, Fixation by long screw

T fractures of the joint, and (4) spiral and transcondylar fractures.

Fractures of the lateral or medial epicondyles of the humerus in the adult may occur individually and one or both may be involved in dislocations of the elbow. Either of these may be displaced into the joint or if completely loose from their attachment may be rotated 90 or 180 degrees and in either instance will require replacement and fixation by operation. Failure to replace either epicondyle into its normal position will limit the motion of the elbow joint after healing has taken place and also will prolong the healing period. Therefore in any of the above situations in which the fragments are displaced, it is felt that early replacement and firm fixation are essential in order that early motion of the elbow joint may be started after a reasonable period of healing (three or four weeks) has taken place. Fixation of these fragments may be by double Kirschner wires, screws, or other means which are familiar to the operator and which will adequately fix the fragments. These condyles are approached through lateral and medial incisions. In all medial epicondylar repairs the ulnar nerve should be identified, isolated and retracted, but it need not necessarily be transplanted if the medial epicondyle can be adequately replaced.

Capitellum fractures may involve a small or a major portion of the capitellum, or the articulating surface may be comminuted. When small fragments are fractured or there is a comminution of the articular cartilage, open reduction should be carried out, the fragments be removed and the joint surfaces be made as smooth as possible by sharp dissection. A large fragment of the capitellum may be fixed in position and held by means of a screw inserted from the posterior aspect of the humerus, the screw passing into and firmly fixing the capitellum in position. (Fig. 225.) The approach is through a posterior or a lateral incision. We prefer this method to that of excision of the fragment. In any injury in which the elbow joint is explored by surgery, the joint should be thoroughly irrigated with saline to remove the cartilaginous and bony fragments and the old blood clot. The part may be placed at rest with a splint for a few days but in this particular

A. B.

Fig. 225. A, Fracture of capitellum and lateral epicondyle. B, Postoperative view showing internal fixation of capitellum by screw inserted from posterior surface into loose capitellum, with two Kirschner wires being used to fix the lateral epicondyle.

type of fracture can be immobilized in a sling and early passive motion be carried out with this protection.

The *fractured trochlea* may be seen individually or in association with other injuries to the elbow joint such as an olecranon fracture and this, too must be treated by early fixation of the fragments in position if possible by suture, by screw or by wire or if there are multiple small fragments these should be removed, the joint surface débrided and the joint irrigated. Fortunately this is a relatively uncommon injury

T fractures into the elbow joint necessitate immobilization of the major fragments. If the frag

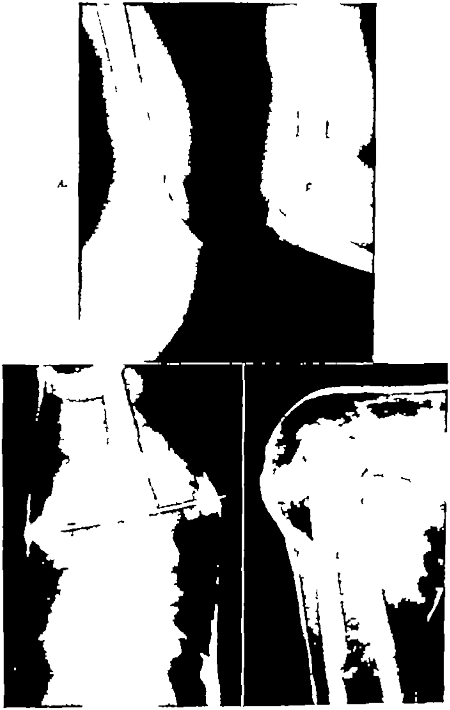


Fig 226. A, Oblique supracondylar fracture of humerus B, Fracture in young individual treated by skeletal traction through the olecranon C, Lateral view of B.

ments are not severely displaced, it is possible that simple traction and a cast with the elbow at a right angle may hold these fragments. A simple cast or a Kirschner wire through the olecranon incorporated in a cast may maintain sufficient traction to hold a simple or minimally displaced and, at times, a severely displaced fracture (Fig 226) However frequent checks should be made and displacement of these fragments which will eventually lead to poor elbow function should have the benefit of open reduction and internal fixation, either by transcondylar screws, single or multiple or by Kirschner wires. On occasion spiral and T fractures into or involving the elbow joint may be adequately immobilized by circumferential wires or Parham bands. When these are applied they should be done so only for immobilization until healing takes place, with the intention of removing them at a later date. These are often difficult fractures to immobilize adequately and if the fragments involve the shaft of the humerus for a very great distance it may be necessary to make a posterior approach to the elbow joint as described by Molesworth or Campbell. The preoperative planning and the operative incision of such fractures are all important in facilitating the surgery as well as in obtaining the desired result, and should be carefully thought out so that the patient may be positioned properly and adequate exposure obtained. We have not felt that blind fixation as described by Miller was feasible.

Transcondylar fractures are likewise individualized and treated according to necessity and if there is displacement or instability it is felt that open reduction and fixation by means of Kirschner wires or screws should be performed the period of immobilization being similar to that of the epicondylar fractures. Closed reduction should be tried once on many of these The period of immobilization is thus prolonged.

OPEN FRACTURES

Open fractures in and about the elbow joint have been reviewed by many authors, including Nicholson Highsmith and Phalen Curry and others It is felt in general, that these injuries should be thoroughly irrigated débrided, and firmly fixed at the time of surgery maintaining all large and useful fragments and closing the wound after a thorough surgical technique has been carried out. It is felt that it is perhaps better to consider an arthroplasty at a later date than to discard any useful bony fragments at the time of surgery How-

Fig 227 Illustrates resection of the distal humerus secondary to open fracture and suppurative arthritis resulting in 70 to 160 degrees flexion and extension and 10 degrees loss of pronation and supination.

ever if large fragments of bone are missing from the joint surfaces it is felt that one of the various types of reconstructive procedures may be initiated at the time of the surgery Many of these reconstructive procedures have been described in the literature but are reserved for correcting late complications. Arthroplasty in our practice has not been as successful as hoped. Resection of the destroyed elbow joint, removing an adequate portion of the lower end of the humerus, has proved most successful (Fig 227) Adequate removal of bone is necessary leaving a flail type of elbow at the completion of the operation. This problem gradually corrects itself The arm is kept splinted at a right angle for three weeks, at the end of which time gradual active motion is started. The use of hydrocortisone injections and their value will be discussed later

DISLOCATIONS

Dislocations of the elbow are mentioned briefly because of the frequent associated fracture. Adequate x ray studies should be made before and after reduction to determine the extent of accompanying fracture if present. Simple dislocations without fracture although there is always extensive soft tissue

A.

B.

Fig. 228. A Dislocation of elbow with associated fracture of the head of the radius. B, Reduction and immediate resection of the head and a portion of the neck of the radius.

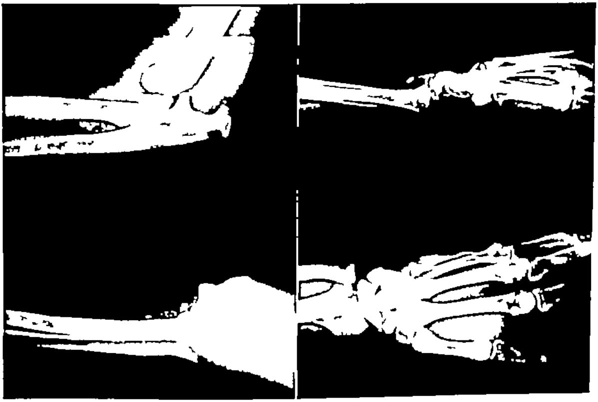


Fig. 229 Illustrates fracture-dislocation of the elbow and a comminuted fracture of the distal radius Treated by resection of the head of the radius. Postoperatively the elbow was placed at right angle and skeletal traction through the first metacarpal was incorporated in the plaster to maintain radial reduction

damage should be treated by reduction and splinting at a right angle followed by relatively early motion. Prolonged immobilization will give a correspondingly fibrosed joint. An early splint with gradually increasing motion in a sling is advisable. Accompanying fracture should be approached surgically as previously outlined, if displaced or interfering with elbow function. Dislocations accompanied by fractures of the olecranon head of the radius, etc. require the usual early surgical approach. (Fig 228) Associated trauma to the shoulder or wrist is frequently encountered in our high-speed age (Fig 229)

COMPLICATIONS

Nerves. The most common nerve to be involved in fractures or injuries in and about the elbow is the ulnar because of its proximity to the bony fragments and the skin. However it is not often severed, even in open fractures. The median, radial and ulnar nerve distribution should be checked in all fractures. Should involvement of any of the nerves be encountered a careful history and examination are of utmost importance. Complete loss of function following a closed fracture indicates severe damage but severance is uncommon. Exploration of the nerve may be delayed if the fracture is to be managed closed. The same is true with partial anesthesia or motor involvement, whether immediate or delayed. Certainly in any nerve involvement, if surgery is *contemplated* which would be the usual case in fractures sufficiently severe to be complicated by nerve injury careful suturing of the lacerated nerve and anterior transplantation of an injured ulnar nerve is advisable. *Splinting* in a position of function and protection of the forearm, wrist, hand, and fingers must be carried out during the period of nerve regeneration. Tardy or delayed *ulnar* palsy means chronic trauma to the nerve from tension, callus, scar tissue or a combination of these. In these instances, surgical intervention with anterior transplantation of the ulnar nerve is indicated.

Vascular Injury The most serious injuries and those warranting immediate operative intervention are those involving the brachial artery. This artery may be caught between the fragments of a fracture of the lower end of the humerus, cutting off the major blood supply in the lower arm, or the artery may be so severely traumatized as to cause a localized area of constriction (arteriospasm) or the vessel may be partially or completely transected. Regardless of the type of injury immediate operation is indicated to preserve the circulation to the forearm. The antecubital approach is used. When possible the lacerated vessel is sutured. At times a constricted traumatized segment may be dilated with stripping procaine heparin, papaverine and sympathetic blocks. If there is any tendency for constriction to recur with handling then the artery should be ligated and the damaged segment resected. Occasionally the soft tissue damage is so great that even re-establishment of arterial supply by artery suture or graft fails, because of inadequate venous return.

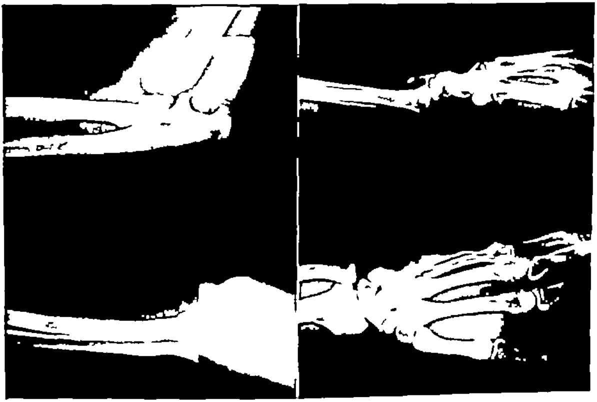
Muscles. When any of the muscles in and about the elbow joint are torn or badly macerated they are débrided and resutured. Tendons are sutured as previously described.

Myositis Ossificans This is a relatively late complication, but clinical evidence of this may become obvious during the third or fourth week. I have seen x ray evidence of calcification at three weeks and at one month When this complication occurs, we have injected the area with tetracaine and 1 or 2 ml. of hydrocortisone and started motion. The physiological effect of the hydrocortisone, other than its anti-inflammatory activity *is not apparent* but we have used this method of treatment in a rather large series of injuries in and about the elbow joint and in some instances of rather late myositis ossificans due to severe blows in the lower portion of the biceps muscle with surprising results. Early calcifications, anterior or posterior to the elbow joint, have been injected with this material which appears to relieve the pain and also has a definite bearing on the progress of the ossification. In several instances subsequent roentgenograms, taken at a seven or eight weeks period have shown a dissolution of these early calcifications. The results of this procedure have been so striking that it has been used in muscular calcifications in other parts of the body with gratifying success.

PERIARTICULAR FIBROSIS

Restricted motion of many elbows following fracture we feel is a result of prolonged fixation for one reason or another Injections of tetracaine or hydrocortisone or both, may aid in improving the motion of these elbows but in all instances physical therapy may be used. It has been the feeling in our clinic that a patient is his own best physical therapist, and they are given exercises to perform to help overcome any restricted motion.

Fig. 228. A, Dislocation of elbow with associated fracture of the head of the radius. B, Reduction and immediat resection of the head and portion of the neck of the radius.



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PERIARTICULAR FIBROSIS

Restricted motion of many elbows following fracture, we feel, is a result of prolonged fixation for one reason or another. Injections of tetracaine or hydrocortisone, or both, may aid in improving the motion of these elbows, but in all instances physical therapy may be used. It has been the feeling in our clinic that a patient is his own best physical therapist, and they are given exercises to perform to help overcome any restricted motion.

Manipulation under anesthesia is never used, and prolonged immobilization is to be condemned. Nor should the patient carry weights, as forcing an elbow only makes it stiffer. We therefore feel that whenever possible the above recommendations of early operation with firm internal fixation, allowing early motion give the most satisfactory end results. In certain cases seen late capsulotomy may provide a marked increase in motion.

CONCLUSIONS

In this diversified series of fractures which have been reviewed in our clinic, occurring in the past ten years we feel that simple fractures may be treated simply but that most fractures with any displacement in or about the elbow joint require early operation with firm internal fixation, preferably with screws extending through both cortices or multiple Kirschner wires, followed by limited periods of immobilization (usually three weeks) and then by active exercises in and out of a sling as indicated.

Complications of these fractures, late and early have been reviewed. Myositis ossificans when discovered and diagnosed is treated early by injection of hydrocortisone which has been surprisingly successful. Late complications and ankylosed elbows have been re-evaluated for reconstruction procedures, arthroplasty or resection of the joint.

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SYMPOSIUM ON TREATMENT OF FRESH FRACTURES OF THE FEMORAL NECK WITH A PROSTHESIS

JAMES E. M. THOMSON M.D
Lincoln, Nebraska

A HISTORICAL PERSPECTIVE OF THE EVOLUTION LEADING TO PRESENT CONCEPT OF TREATMENT

One of the oldest problems of historical medical discussions must have been management of fresh fractures of the neck of the femur. Allusions to disabling acute trauma of the hip and methods of treatment must have been recorded in ancient medical writings. It was not however until 1822 when Sir Astley Cooper published his text on fractures that we find the observation that, since fractures of the neck of the femur seldom healed, it was better to obtain early ambulation without weight bearing for the preservation of life in the aged at the risk of nonunion.

Traction and sandbags remained the treatment of choice until Royal Whitman, of New York, at the beginning of the twentieth century added the factor of internal rotation and reduction to that of the abduction spica cast. By this method Whitman obtained 35 per cent union.

Internal fixation was applied as early as 1850 by Langenbeck and later by several others. There were occasional successes, but the tissue reaction to the metal used often resulted in failure.

The use of autogenous bone pegs as a method of internal fixation was popularized in this country by Albee as early as 1911 but frequently the pegs broke and nonunion developed.

In 1931 Smith Petersen and associates reported a real measure of success after reduction and internal fixation with a three flanged nail which prevented rotation of the head of the femur.

With improved alloy constituents in the nail, there was little or no tissue reaction.

King, Henderson,[7] and Johansson introduced the idea of Kirschner guide wires across the fracture after reduction, over which a cannulated Smith Petersen nail was threaded and driven home. The wires not only served as a guide but two or more wires through the neck and into the head prevented rotation of the head during the insertion of the nail.

Later multiple pins and wires were introduced by Moore[8] and by others as a method of internal fixation. Thornton and Sandison recommended a lateral femoral plate to give better stability to the flanged nail. The use of a cortical bone graft above the tri flanged nail was recommended with the idea that it would give additional stimulus to bone healing.

All these methods are accepted and will be I believe for a long time since they *result in union* in something like two-thirds of the cases.

This leaves about one third of the femoral neck fractures that will go to nonunion no matter how carefully they are nailed and stabilized.

Also among the two-thirds that do heal there is a possibility particularly in old people of late complications, such as aseptic necrosis and degenerative

changes in the form of osteoarthritis, which result in painful disabled hips.

It was the dissatisfaction of many surgeons with these approved methods of treatment particularly in the case of older people that led to the trial of a hip prosthesis as a final procedure in re-establishing a functionally stable hip thereby escaping the uncertainty of bone union and late complicating degenerative changes. The rationale of this procedure is based on the observations of hips functioning fairly satisfactorily following salvage procedures, in which an endoprosthesis has been used for various pathological conditions.

In the late twenties Hey Groves used an ivory hip prosthesis in treating a femoral neck fracture. This prosthesis was very similar in shape to the initial type that Judet [2] popularized about 1948.

Enthusiasm for the Judet method became itself a disease so contagious that it spread like wildfire through Europe and America. Every kind of surgeon everywhere was trying this panacea for anything and everything in hip pathology including femoral neck fractures. Many results were disappointing because of fracture of the acrylic, and other mechanical failure of the substances used as well as resorption of bone.

These unfortunate circumstances led to modifications inspired through the creative initiative of many orthopaedic surgeons. Among them was my own light bulb prosthesis [13] which in the beginning we cast in plastic on a tri flanged Smith Petersen nail. After eight years we still have a few of these around in patients who are living well, and happy. Later however being able to obtain the same prosthesis in Vitallium gave us far more assurance of its lasting qualities.

The weakness of all the short-stemmed prostheses, including the light bulb type is the difficulty in accurately seating it in the neck at the proper angle with a stem long enough to impinge into the lateral femoral shaft.

It was recognition of this weakness that again stimulated the inventive genius of our surgeons, to the extent that there are some forty or fifty types of prostheses now available. The more popular are those with long medullary stems that give the prosthesis stability through the shaft of the femur. The acrylic prosthesis has lost face at least in our country and has been replaced by Vitallium and to a lesser extent stainless steel.

With the foregoing perspective of the historical evolution of our present concept of accepted methods of treating femoral neck fractures and this summary of the trends and types of prostheses and their fabrication we now wish the panel of able discussants to present to you their ideas in regard to the subject of this course.

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STATISTICAL REVIEW

REVIEW OF PAST SURVEYS

Before discussing any of the material gained from the statistical survey it might be well to review briefly those statistics given at the 1958 Academy meeting (Tables 16 to 20)

It should be noted that in these statistics there was no specific breakdown concerning the use of a prosthesis in fresh fractures, so the following statistics, with results that were limited strictly to the use of prostheses in fresh fractures, may be expected to vary considerably Also it will be noted that the tables presented here (Tables 17 through 20) give data based on the number of men answering the questionnaire rather than the number of patients, except for Table 20 on the over all total number of prostheses used

It is quite apparent there has been a marked shift toward the use of an intramedullary stem type of prosthesis

Table 18 shows the survey results concerning present indications for the use of a prosthesis, in general from these it is clear that the most common use today is in the acute fracture

Table 16 Survey of Femoral Head Replacement Prostheses

Response	Physicians Answering
Yes	453
No	88
Survey incomplete	10
Total	551

Table 17 Prostheses Used

Type	Number Reporting
Type now being used	
Moore	195
Thompson	134
Eicher	76
Naden-Reith	19
Minneapolis	10
Others	20
Type formerly used	
Judet	137
Eicher	97
Naden-Reith	64
Thompson	30
Moore	24
Others	20
Reasons for change of type	
Judet wobble	27
Acrylic, wore or broke	25
Intramedullary better more stability	19
Moore, rotation much better	18
Nylon failure or fracture	12
Others	26

Table 18 Indications for Use of Prosthesis

Subcapital fracture (60 years or over)	225
Aseptic necrosis and fragmentation	186
Nonunion	178
Hypertrophic arthritis, traumatic malum coxae senilis	165
Rheumatoid arthritis	51
Others	[illegible]5

It will again be noted that most men categorically state that the age of the patient should be 60 to 70 years or older which is again brought out in Table 19 the contraindications for prosthetic use the second most common being use of a prosthesis for an acute fracture in a patient under 60 years of age

Table 19 Contraindications for Use

Infection (including tuberculous)	156
Acute fracture (under 60 years of age)	110
Adolescence	65
Debility poor risk	43
Rheumatoid arthritis	38
Others	43

Because the rest of the survey is not sufficiently broken down, statistically relative to fresh fractures only further statistical data will not be presented from the survey except to point out that according to this one survey 10,274 hip prostheses have been used (Table 20)

Table 20 Number of Patients With Prostheses

Unilateral	10 059
Bilateral	96
	10 155
Doctor reporting "No" but had used prostheses	119
Total	10,274

REVIEW OF PATIENTS TREATED AT UNIVERSITY OF ILLINOIS

At the University of Illinois we have used prostheses for fresh fractures in only seventeen patients. Their age range was from 35 to 89 years. It should definitely be mentioned here that the one patient 35 years old had a metastatic carcinoma The procedure was used to aid the patient and her nursing care and it accomplished both very well. She survived only one year but was walking fairly well and was quite comfortable See Table 21 for these results.

*Table 21 Results Obtained at University of Illinois With Prostheses Used in Fresh Fractures**

	Metal	Nylon	Acrylic
Excellent	2		0
Good	4		2
Fair	2		2
Poor	1		3

*The one patient for whom this treatment was used under special considerations (see discussion) has not been included in the tabulation

Sometimes associated fractures may be an additional indication for the use of a prosthesis.

Since I have presented two Academy surveys on hip prostheses I have been accused of being a very ardent advocate of them. While I personally feel there is a definite indication for their use and particularly so in fresh fractures the following statistics (Tables 22 and 23) from my own private practice will show I believe that I have not used prostheses indiscriminately

Table 22 Private Practice Treatment of Fracture of Hip Other Than Prostheses

Number of Patients (49)	Surgical Treatment
33	Smith-Petersen nail
13	Pins
1	Whitman
2	None

Age: 46-83 years (average 69 1 years)

Sex: 33 females, 16 males

Hip:

Males	8 right	8 left
Females	17 right	16 left

Date of beginning of series 1938

Table 23 Private Practice Treatment of Fracture of Hip With Prostheses

Number of Patients (21)	Prostheses
15	Moore
6	Eicher

Age: 56-87 years (average 76 9 years)

Sex: 17 females, 4 males.

Hip:

Males	3 right	1 left
Females	9 right	8 left

Date of beginning of series, 1952.

A review of the literature revealed ten papers (see References) on the use of prostheses in fresh fractures. In these papers there are reported 231 patients treated in this manner but several of the papers do not give statistics. The over all impression however is that this method of treatment gives surprisingly good results.

COMPLICATIONS

We will now return to results of the survey for a discussion of complications. Dislocation of the pros-

thesis was the most common and as seen from Table 24 a total of 321 men out of the original 551 reported dislocations.

Table 24 Dulocation of Prosthesis

Lateral	7
Anterior	111
Central (th ough acetabulum)	41
Posterior	97
Total	321

Central dulocation through the acetabulum has been a very difficult problem to solve One method that we have used twice is to remove the prosthesis, pack the acetabulum with an iliac graft, and then insert the next smaller prosthesis. The leg was kept in traction for about one month and then motion allowed but no weight bearing for six months The patient has, clinically an excellently functioning hip two years later

Breakage of the prosthesis has presented another type of complication, as illustrated in Table 25

Table 25 Broken Prostheses

Type	\	Location
Judet	41	Stem-neck
	29	Head
	11	Rim
\ylon Judet	9	Head
	2	Stem
\aden-Reith	8	\eck
	5	Stem
Eicher	14	Stem
	10	\eck angle
Collison	1	Stem bent
	11	Screws

With the exception of the original stainless steel prosthesis of Eicher all of these were short stem types. With the trend toward the intramedullary type this complication should rapidly diminish there having been but one Moore and one Thompson reported so far as being broken but five Scuderi and four Lippman prostheses have been reported broken There are insufficient data to let us evaluate the new Eicher type made of Vitalli m

The number of additional fractures that these patients have sustained as a result or complication of the surgical insertion of a prosthesis (acetabulum, 8 femur—early 178 and femur—late 49) rather speaks for itself

It was also indicated that 251 out of the 551 reporting had encountered at least one infection.

The occurrence of a phlebitis was reported by 157 men.

The fact that 218 men had immediate mortalities to report is not too surprising since primarily—whether for fresh fractures or reconstructive surgery—the operation has been done on an older age group

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C F FERCIOT M D
Lincoln Nebraska

PRIMARY PROSTHETIC REPLACEMENT IN FRACTURES OF THE FEMORAL NECK

Our moderator has reviewed the history of treatment of fractures of the femoral neck, and it must be concluded that there is as yet no perfect treatment for this fracture. At the present time we have to deal with this problem fracture to the best of our ability guided by past experience and with minds open to the possibilities of improved methods.

EVALUATION

In spite of strong opposition it must be admitted that primary prosthetic replacement has gained in popularity during the past several years. With increased experience in this field there is a tendency to widen its field of indications, and it is certainly time to re-evaluate this problem and to more clearly define just what can be expected from the method and to determine just what its limitations may be

Our experience with primary prosthetic replacement dates from 1950 and comprises a series of ninety four cases up to the end of 1957 (Tables 26 to 28) As a result of our experience we have arrived at the basic premise that primary prosthetic replacement should be used in every case where it promises to be the best method of management for that particular patient Conversely it should not be used in any case for which there is a better method of management available. It is thus evident that it is necessary to weigh the possible advantages of this method of management against the obvious disadvantages, for each individual patient. The responsibility for guiding therapy rests directly with the surgeon, and there are two questions to be answered without equivocation (1) Can this patient afford to invest from six to twelve months in attempting to obtain bony healing? (2) Is that a wise investment for this patient? If the answer to either of these questions is "no" then use of a prosthesis should be evaluated. This group includes cases wherein satisfactory reduction and internal fixation are not likely to be obtained, or where the patient s general condition is such that he cannot reasonably invest from six to twelve months of time in an effort to obtain bony healing

In my opinion the greatest disadvantage of prosthetic replacement lies in the fact that it does not offer the possibility of obtaining as good a degree of functional capacity as might be gained from a well-healed fracture. The necessity for functional capacity does vary from one patient to another and in many instances it is felt that the advantages far outweigh this drawback. Evaluation of the probable functional capacity of the patient after prosthetic replacement is of considerable importance and will be further discussed as part of the consideration of results and complications.

Preoperative care is essentially the same as for any major surgery Early supportive care is indicated and surgery should be deferred until the general condition of the patient has stabilized and has been evaluated. It is our conclusion that needless delay should be avoided, as there is an optimal time for surgical treatment if this is not recognized, further delay tends to result in complications that might otherwise have been avoided.

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Table 24 Dislocation of Prosthesis

Lateral	72
Anterior	111
Central (through acetabulum)	41
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Central dislocation through the acetabulum has been a very difficult problem to solve. One method that we have used twice is to remove the prosthesis, pack the acetabulum with an iliac graft, and then insert the next smaller prosthesis. The leg was kept in traction for about one month and then motion allowed, but no weight bearing for six months. The patient has clinically an excellently functioning hip two years later.

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Preoperative care is essentially the same as for any major surgery. Early supportive care is indicated and surgery should be deferred until the general condition of the patient has stabilized and has been evaluated. It is our conclusion that needless delay should be avoided, as there is an optimal time for surgical treatment if this is not recognized further delay tends to result in complications that might otherwise have been avoided.

Table 26 Evaluation of End Results

	Living		Dead		Both	
	No.	%	No.	%	No.	%
Excellent	7	14 9	3	6.4	10	10 7
Good	16	34 1	5	10.6	21	22.3
Fair	19	40 4	11	23.4	30	31.9
Poor	5	10 6	28	59 6	33	35 1
Total	47		47		94	

Follow-up Period of Living Patients

No. Cases	Follow-up (yr)
16	6-8
10	3-5
21	1 2
47	Average 3 yr 8 mo.

Table 27 Time of Deaths Within Group of 32 Patients Unable to Walk Because of Associated Conditions

During first week	4
Additional, during first 3 months	8
Within next 9 months	8
Total during first year	20

The technique of operation has already been discussed. However I would like to summarize briefly the conclusions of our group In general, we have come to favor the posterior or "southern" approach to the hip joint and also to favor the use of a suitable intramedullary prosthesis (Tables 29 and 30) In selected cases we still find the light bulb prosthesis suitable perhaps because we have had more experience with it. We frequently feel that operative time can be shortened and surgical shock lessened by using it in a poor risk patient. A repair of the joint capsule and short rotator cuff is practiced and the patient is returned to bed with the leg in external rotation and slight abduction Supportive measures are used as indicated for the individual patient and early activation is encouraged as rapidly as the patient is able to accept it

Progressive activity is guided by the individual patient's response and we feel that continued supervision is necessary In many of our patients there has been no possibility of a return to active walking without support and in some cases they are not physically able to get up even on crutches. The relief of the painful hip, however allows them to be cared for in greater comfort and with greater facility and makes it possible for these patients to be returned to their homes or to nursing homes within a short period of time In many instances we have been surprised by the degree of activity that these poor risk patients eventually develop However we would caution against unsupported weight bearing in the case of the weak or debilitated patient until his muscular control of the extremity is sufficiently strong to avoid the danger of dislocating the hip.

Table 28 Cause of Deaths During First Year Within Group of Patients Able to Walk

Cardiovascular disease	7
Pneumonia	2
Cerebral accidents	2
Total (average age 78 yr)	11

Table 29 Types of Prostheses Used 1950-1957

Light bulb, acrylic	33
Light bulb, Vitallium	43
Intramedullary	20
Total	96

Table 30 Types of Surgical Approaches Used 1950-1957

Anterior	5
Gibson	35
Posterior	56
Total	96

Table 31 Early Postoperative Complications

Dislocations		4
Surgical deaths		2
Cerebral accident	1	
Pulmonary embolism	1	
Infections		0
Foot drop		2

COMPLICATIONS

The general complications that have arisen after primary prosthetic replacement are essentially the same as those that are associated with treatment of the fracture by reduction and internal fixation. There were two patients who died on the day of surgery one as the result of a pulmonary embolism and one as the result of cerebral accident (Table 31)

Postoperative dislocation of the prosthesis occurred in four patients. A review of these cases indicates that this complication tends to happen in two types of patients. first those having a paralyzed or spastic extremity which is difficult to control and tends to pull up into flexion and adduction and, second, elderly patients with general muscular weak

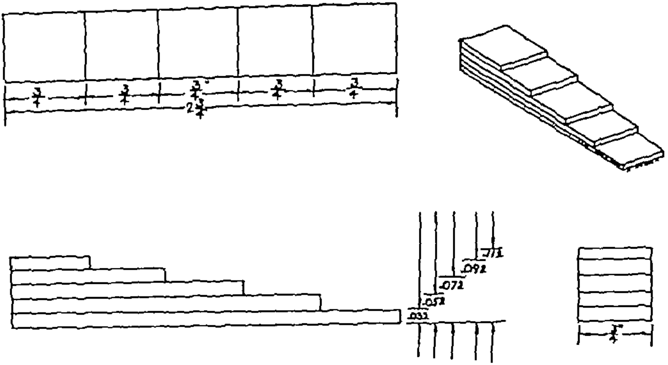

Fig. 230. Detail of aluminum filter used in bone density measurement.

ness and debility in which case dislocation occurs on attempted weight bearing because the patient is not strong enough to control the extremity No recent dislocations have occurred in cases where the posterior approach has been used and where an intramedullary prosthesis has been applied. In any instance where it is felt there is a factor predisposing to dislocation, such as hemiplegia, Parkinson's disease or tightness of the adductor muscles, precautionary measures are taken, which consist of a subcutaneous adductor tenotomy and/or boot casts to control rotation. Surgical repair of the hip joint capsule is practiced as well as repair of the rotator muscles. In the elderly debilitated patient we encourage activity but do not attempt unprotected weight bearing until it is felt that muscle strength is adequate

Loosening or settling of a prosthesis in the upper end of the femur will tend to occur in any patient where the stress between the prosthesis and bone is sufficiently strong and persistent to result in a pressure necrosis of the bone. It is our conclusion that this factor is probably the major cause for the limited functional capacity that is found after prosthetic arthroplasty A transfer of body weight and muscle stresses to the upper end of the femur through a rigid metal prosthesis obviously results in abnormal stress factors at the point of contact. Ideally a prosthesis should transmit body weight equally throughout the entire upper part of the bone and should have the same factors of elasticity as the bone itself Our early experience with the light bulb prosthesis demonstrated great individual differences in the amount of stress that the bone would tolerate in individual patients. Observations at the time of surgery demonstrated wide differences in the hardness and strength of the bony tissues and it was observed that in those patients who demonstrated the findings of osteoporosis there was less resistance to mechanical stresses and a greater tendency to develop loosening and wobble of their prostheses. The development of the intramedullary type of prosthesis is a definite step toward better stress distribution. However I am convinced that at the present time there is no doubt but that the patient with a prosthesis must accept a considerable limitation in functional capacity In reviewing our problem cases in 1954 it became evident that both a loosening of the prosthesis and bone resorption tended to occur in the older patient who showed signs of osteoporosis and in whom nutrition was poor A review of the patients in the younger group also demonstrated that even where bone density appeared good and the general nutrition excellent, there would develop some loosening of the prosthesis if the patient were very active. On the other hand, a number of patients who had developed some loosening of the prosthesis went on to a fair degree

of functional capacity following a graduated activity program and consideration of nutritional factors. Observations were that bone strength was related to the nutritional status, to the metabolic balance, and to the physical activity of the patient

In attempting to develop an index of bone density or strength, we have followed the suggested program of evaluating the radiographical density of the bones of the hand as compared to the shadow cast on the roentgenogram by a standard and known thickness of aluminum. The gauge which we are using at present and which has been found to be satisfactory is simply made being ¾ inch in width by 3¾ inches in length. It consists of five steps of thickness, each ¾ inch long The first is 0.032 inch thick with each additional step being 0.020 inch in thickness. We refer to this as the density gauge or the densometer (Fig 230) This gauge is placed on the roentgenogram by the side of the hand and a routine posteroanterior exposure is made being careful not to overexpose the film. When the film is dry the relative density of the base of the proximal phalanx of the mid finger is compared with the shadow cast by the density gauge Readings have been found to range from a low figure of 2 in the osteoporotic individual to a high of 4.5 to 5 in a young adult. This permits a graduation of seven degrees by means of a simple technique After using this procedure in a variety of cases for the past eighteen months I am convinced that it does have a useful clinical application Readings of less than 3 are found in cases of definite osteoporosis. These are routine in elderly bed patients and frequently are seen in older females, particularly those who have had a surgical menopause. In a series of nine hip prostheses for nonacute conditions readings were found to vary between 3 and 4.5 In eight cases of primary prosthetic replacement for fracture in patients ranging in age from 46 to 82 years there was a variation of from 2 to 4 the lower reading being recorded in bed patients except for one instance in which a reading of 2 was observed in a 75-year-old lady who had developed severe loosening of her light bulb prosthesis Bed patients did not develop bone resorption, even though their density factors were low In no instance was there a grading of excellent without a density factor of 3.5 or above In this group of eight patient significant loosening of the prosthesis had occurred in only two cases However even in the more active patient who were able to walk without support of any kind some reaction about the prosthesis was evident and it is my impression that these individuals were remaining within the limit of their bone tolerance to stress. Without doubt, degenerative changes do occur at the points of contact between the prosthesis and bone, but the bone metabolism can be such that a continuing repair of the bony structure prevents the development of progressive necrosis and loosening of the prosthesis.

Our study in regard to bone density factor is still incomplete and of short duration, but I am convinced that it does offer an index of the degree of resistance that can be expected from the bone of the individual patient to the stresses of weight bearing through a prosthesis. In a patient with marked osteoporosis it would certainly be unwise to encourage strenuous weight bearing and certainly there would be an indication for therapeutic management directed at improving the bone metabolism and gradually reactivating the patient. Admittedly our approach to the use of prostheses in the treatment of fresh fractures of the neck of the femur has been conservative, and I am sure that if younger patients were treated by primary prosthetic replacement a very satisfactory functional result could be expected in a high per cent of cases, provided the patient appreciates the fact that he must accept a limited functional capacity Under special circumstances I can understand that primary prosthetic replacement may be indicated in a younger patient but in general would urge conservatism.

Among the late complications that may cause embarrassment are fractures in the region of the prosthesis or in the shaft of the femur adjacent to it. We have had the opportunity of seeing two such cases in the past year and, while they were successfully managed, they did present special problems in management. In summary let me say that none of us are entirely satisfied with the clinical results following primary prosthetic replacement for fractures of the femoral neck but the fact that so many of us are interested in the problem indicates at least that this method does have a place in the treatment of this condition. In properly selected cases I am sure it is the treatment of choice It seems certain that with increasing experience and with further improvement in design and technique, as well as a better understanding of bone metabolism, there will be a gradual broadening of the indications for its use. For the present, I believe we should reserve use of primary prosthetic replacement for only that patient in whom we sincerely feel that it is the best method of treatment available

PALMER EICHER M D
Indianapolis, Indiana

USE OF A PROSTHESIS IN THE FRESH INTRACAPSULAR FRACTURE OF THE HIP

Prolonged experimentation resulted in a replica of a femoral head and neck which was used in a patient nearly nine years ago. This prosthetic device was made of type 316 stainless steel. It was designed to restore the articulating mechanism of the hip. Evaluation of the early results obtained revealed unusual and gratifying success.

REPORT AND EVALUATION

I now have sufficient information on twenty four cases to make a detailed evaluation. I have perhaps five or six more cases which belong in this fresh fracture classification but my information on these is not adequate to make a worth while long term appraisal.

The youngest patient in this group was 68 years old at the time of surgery and the oldest was 95 with the average age being 77¾ years. The longest follow up time is eight and one half years and the shortest six months. Fifteen cases have been observed for more than five years. Eleven patients have died since the surgery was performed. In thirteen cases an acceptable result was obtained which made ambulation possible without the aid of a cane or crutch. Since each case presents its own unique problem, I have decided to judge each case separately and, in retrospect, decide whether or not I would use the prosthesis in the light of the long term result obtained. My conclusion is that I would use the same procedure in twenty two cases and that I would not use it in two cases. In these two, a satisfactory mechanical result was obtained but the patients made little or no effort to use the hip.

TECHNIQUE

I have used three surgical approaches. Each has its advantages and disadvantages, but I prefer the lateral approach, going through the anterior part of the capsule. It is an easy approach and in most cases requires very little releasing of abductor muscles to gain access to the joint. This makes the post operative care and recovery easier and quicker without undue loss of the power of abduction. One has only to prevent adduction of the extremity operated upon.

The anterior Smith Petersen acetabular approach requires more time and in the postoperative period it is necessary to prevent outward rotation of the leg during the first two or three weeks.

The posterior approach—actually a posterior approach to the capsule—requires the least operative time but complications have caused me to abandon it. Postoperative dislocation of the prosthesis when the hip is flexed has occurred too many times and, furthermore, trauma to the sciatic nerve due to the proximity of the operative site is a real danger. I believe that the proper anteversion can be more accurately determined when the anterior capsular approaches are employed than when the posterior approaches are used.

INDICATIONS

A pathological fracture of the neck of the femur presents an ideal situation for primary use of a prosthesis. A severe deformity due to arthritis and a fracture affords another opportunity for its use. When primary nailing fails to hold the reduction throughout the first days or weeks, before there is sufficient time for healing with individual factors considered, a prosthesis is well indicated.

Another condition is the neglected fracture in which the prosthesis is used as a first treatment. Cases of delayed diagnosis and misdiagnosed cases belong in this group. Every so often, an impacted fracture resulting in knee pain only is diagnosed late depending upon how much the injured hip is used. In one case the diagnosis was made three months after the original injury. The patient was 72 years old; the prosthesis was used to restore motion and stability of her hip. In the other case, the patient did not seek medical attention until four weeks after the original injury.

The last indication I wish to discuss is the fresh fracture with immediate diagnosis and surgery performed within the first few days using a prosthesis. If a prosthesis is used in such a fracture, the patient should be 75 years or older. The decision to use a prosthesis instead of nailing a hip in a patient such as this requires careful consideration of the whole clinical picture. Each case should be decided upon the sum total of the problems at hand. The general condition may be such that it is clear that only one surgical procedure will be tolerated, or perhaps the patient or his relatives may indicate that only one surgical procedure is all that will be granted. An extreme desire on the part of an aged individual to return home to an accustomed routine of living may justify the use of a prosthesis. An example is the one 93-year-old man for whom I made such a decision and used a prosthesis. He came to my office two weeks ago at my request for the purpose of examination and to obtain three-year follow-up roentgenograms. He is now 96 years old and walks very well without the aid of a cane or crutch.

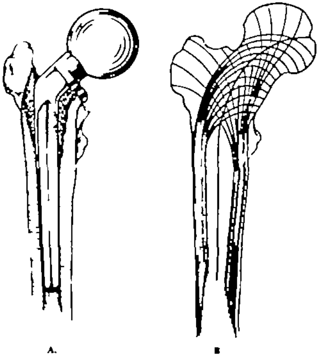
A. B.

Fig. 231. A, Drawing showing sagittal section of prosthesis in situ. B, Drawing of stress lines of normal proximal femur.

The basic idea of harnessing the remaining femur with a prosthesis simulating the normal lines of force has not altered (Fig. 231). However, experience has shown deficiencies in design, shape, and size, and has led to many changes. Even now new features are being added which, to this date, have not been tried in a patient. The ideal and perfect hip prosthetic device is not in existence at this time. We have made great progress. Many hips have been restored to normal or near normal function. Others have been failures—indeed, too many.

A review of the basic features includes these points.

1. A sphere of proper size to fit the acetabulum must be selected. Enough sizes should be at hand to actually try the head in the acetabulum before insertion into the femoral shaft. The size producing a sucker effect is the correct fit. Whether the replacement head should be shaped like the normal femur or should be a sphere, as it is now, is of course another unanswered question.

2. A collar abutting the calcar femorale at right angles appears to be essential. It is correct from a mechanical aspect. Experience has shown that the bone holds up well under this collar so placed. Much effort has been made to prevent minute rotation of the prosthesis. I believe this will have to be accomplished between the collar and the remaining neck. Gross rotation may be prevented by the design of the stem, but the troublesome minute motion must be stopped under the collar. The new design has a dowel type projection which appears to solve the problem.

3. The neck of the prosthesis has been shortened and the angle raised to 135 degrees. The reason for

this change is to avoid the chance of producing an increased over all length of the femur. Also, the femoral shaft weight bearing line is brought nearer the midline of the body. This feature should please those who like osteotomies.

4. The intramedullary extension has been altered many times. A perfect fit, to completely fill the canal, is not possible. It is also not desirable. If the stem is too small and especially if it has too much taper, it will wobble. The latest change has an undulating wave on the outersurface which appears to lock the prosthesis immediately.

MATERIALS

The new device has been fabricated of SMO steel type 316, of Vitallium and of Titanium. Other new materials are in the experimental stage. So far I have no proof that any one is superior to the others.

COMPLICATIONS

The hip reconstructed by using a prosthesis too often has not been pain free, and even though failures are a disappointment they are most helpful in pointing the way for improvement.

Fig. 232. Seven years after insertion of prosthesis. This femur had shattered in an explosive manner at the time of insertion.

Fig. 233. Fracture of prosthesis, demonstrating metal failure.

In the very first patient in whom I used a prosthesis for a fresh fracture, in October of 1950, the upper third of the femur shattered in a spiral, explosive manner (Fig. 232). Fortunately the stem of the prosthesis reached into the distal remaining fragment for 1 inch. The pieces of the upper portion of the femur were placed together as well as possible and held with three Parham bands. The fracture healed. The patient now has been walking well without a cane for eight and one half years, and without pain. When I presented her to Dr. W. Blount he asked her if she had pain. She became highly indignant and days later called me to express her displeasure about the question. What he did not know is that she is a devout Christian Scientist.

Besides pain, another complication is dislocation of the metal head. Rotation of the prosthesis may be blamed in part; however, the surgical approach must also be incriminated. This has occurred in two cases when the posterior approach was used. In one case, it was not recognized prior to surgery that the nail used for primary fixation was driven into the posterior lip of the acetabulum instead of the head. There was no posterior lip left. Removal and resuture of the outward rotators doomed the hip to dislocation the first time the femur was flexed.

Metal failure has been a problem (Fig. 233). Early testing indicated sufficient strength. However, actual experience resulted in metal failure in some cases. None of the twenty-four cases reported has resulted in metal failure. I took the liberty of borrowing complications because failures can and have occurred in the use of the prosthesis in fresh fractures. A change in design and shape has apparently

Fig 234 Wandering acetabulum developed because of improper seating of prosthesis against the base of the neck.

Fig 235. Improper seating due to increased length. Note pelvic tilt and adducted position of femur

Fig. 236. Insecure prosthesis as a cause of pain. Compression appl ed to the foot of the ffected leg Note top of greater trochanter has migrated superiorly and laterally Compare w th Fig 37

Fig 237 Same patient Traction applied to leg t time of -ray examination. Not top of greater trochanter pulled inferiorly *Also not* calcar femorale pulled way from underside of collar

added sufficient strength The behavior of metals in certain solutions and temperatures still reveals unusual and not too well understood freakish changes. Stress corrosion is one such behavior

Improper seating of the prosthesis must be incriminated. This ties in with the next unacceptable hip illustrated (Fig 234) I believe that the pain in this hip is due to increased leg length pelvic tilt, adduction, and loss of full extension (Fig 235) The hip is obviously under constant strain. If a hip such as this is actually used enough, over a long enough period of time one of two things can and often does occur: either the stem breaks or a wandering acetabulum develops. This still further increases pain and restriction of motion especially in abduction and extension.

A loose insecure prosthesis in the femur will surely produce an unsatisfactory hip. This, I believe is still an unsolved problem. This complication is manifest in several ways. First, it results in a painful hip. Also, a painful click or clunk occurs. Roentgenograms are helpful two anteroposterior views, one push and one pull, will reveal the difficulty (Figs. 236 and 237) Not only is there a wobble of the stem, but also there is a rotary movement in the prosthesis in relation to the femur Passive rotation of such a hip produces pain.

Much has been done in an effort to correct this troublesome aspect. Since there is so much difference in the size and shape of the upper femur from one individual to another it is impractical to have sufficient stem sizes to fill each one completely Furthermore, it is not desirable—there is too much danger of fracture on insertion. Even in a tight fit, there is too often minute motion which, with use, can become gross movement. The only recourse then is to try to lock the prosthesis securely by its shape rather than its mass. I have made many changes in shape, or contour and have increased the angle of the metal neck for the purpose of correcting this troublesome problem. Also, the length of the neck has been shortened as much as it can be and still keep the trochanter from coming in apposition with the roof of the acetabulum.

The latest design has not been tried in a patient. I had hoped to do so by this time. This design has a sweeping undulation on the outer boarder of the stem. It appears that about three different degrees of curves should result in a snug fit in the various sizes of femurs encountered. To stop the minute rotary motion, a dowel type projection under the collar has been added. In the cadaver femurs it has produced an immediate secure locking

In addition to the causes already mentioned, I wish to add another namely hyperemia for any reason. I suggest the presence of a low-grade infection in two cases. In one case the wound became red opened, and drained a while five months after surgery This hip had become painful prior to the drainage.

One must also question how acceptable the metals we are now using may be to the tissues involved. A newly formed capsule and synovial tissue taken from a hip joint in which a prosthesis had been placed showed inflammatory reaction with no evidence of infection. Two of the most pain-free and usable hips in my series are in patients walking on prostheses made of Titanium.

Abductor weakness with resultant repeated strains of the hip may well explain some painful unusable hips. In one instance I transferred the origin of the vastus lateralis for additional power with beneficial effect.

SUMMARY

The prosthesis has, in my practice, proved a highly satisfactory method of treating the fresh intracapsular fracture of the hip in certain cases.

The described prosthesis has been modified many times in the past ten years for the purpose of avoiding further unacceptable results. A secure and immediate locking of the prosthesis with the femur is necessary and this must be accomplished by the design and not by its mass alone. The available materials apparently are satisfactory when used properly Further search for new materials however may well contribute to better results.

MARK B COVENTRY M D
Rochester Minnesota

FRESH FRACTURE OF THE HIP TREATED WITH PROSTHESIS

In April, 1956 I reported our experiences at the Mayo Clinic with replacement of the femoral head with a prosthesis.[1] At that time the indications, complications, results, and conclusions of our experience based on 185 operations in 171 patients, were presented. Only ten of the 171 patients were operated upon because of fresh fractures of the femoral neck and these operations were performed in 1952 and 1953 Since that time twenty additional prosthetic replacements have been carried out in patients with fresh fractures of the femoral neck. The present report concerns these thirty patients.

Considerable experience has accumulated in the past several years on use of the femoral head prosthesis. Ghormley[2] summarized the pertinent current literature on this subject up to Jan. 1 1958 There is common agreement in which I fully concur that there is no complete substitute for the normal femoral head it therefore follows that the prosthetic replacement operation is a compromise procedure (Fig 238) I agree with Goday Moreira who expressed the opinion that the femoral head prosthesis is too frequently used, probably because of the apparent simplicity of the technique as compared to that of osteosynthesis or bone graft, which require use of x ray study during operation. But use of roentgenograms is not the only complicating problem in "nailing" hips. After proper reduction, meticulous operative technique is necessary All of us are familiar with the complications that may arise even after proper reduction and internal fixation. Therefore we must carefully weigh true indications for the prosthetic operation against the expediency of the procedure, and perhaps we can come to some conclusions about the matter

For present purposes a fracture is considered fresh" if it has occurred within forty days prior to the time of replacement with a prosthesis.

INDICATIONS

The selection of proper patients for treatment with a femoral head prosthesis is the chief problem, and will remain so until further clinical studies are made and additional experience has accumulated. Certainly one should not wish to use a prosthesis in the younger groups, for it is not known whether the structure will hold up indefinitely Nor should one use a prosthesis if adequate reduction and fixation of the fracture can be obtained by the usual methods. One should also not use a prosthesis if the patient will not be able to walk again, for probably little or nothing is to be gained by establishing a fairly normal relationship of the hip joint if weight bearing is not anticipated in the future.

Some fairly definite indications are presented in Table 32 and elaborated briefly below

1 Fracture of the femoral neck with dislocation of the head at the same time. Although this is rare, we have treated one such patient at the Mayo Clinic by femoral head replacement. A nonviable head would be anticipated as a result, and replacement with a prosthesis seems indicated in this situation

2 Comminuted fracture involving the femoral

Table 37 Relative Indications for Use of a Prosthesis of the Hip in Fresh Fractures

1	Fracture-dislocation
2.	Comminuted fracture
3.	Pathological fracture
4	Irreducible fracture
5	Increase in vertical angle of fracture
6.	Delay between time of fracture and definitive treatment
7	Fracture that "falls apart"
8	Ability to walk again
9	Age of patient

head and neck. Usually such a fracture cannot be adequately reduced and held with internal fixation. We have used a *femoral* head *prosthesis* in one such patient.

3 Pathological fracture. This type of fracture may be treated best in some instances by replacement of the femoral head. Pain is usually relieved but the bone at the base of the neck and distally must be sound to support the prosthesis. Operation gives one a chance to verify the diagnosis and to determine the type of tumor present. The decision whether to insert a femoral head prosthesis or to do some type of nail or blade-plate fixation can then be made. We have treated one such patient showing metastasis from a carcinoma of the breast to the pelvis, although no metastatic lesion was found in the femoral neck at the time of operation (Fig 239)

Fig. 238. Moore prosthesis in the right hip subsequent to fracture with nonunion, and fixation of the left hip with a Smith-Petersen nail subsequent to acute fracture. The result was classified as good, but the patient had slight pain, a slight limp and limitation of flexion to only 90 degrees on the right. There were no limp, no pain, and no restriction of motion on the left. This case illustrates that a well-healed fractured femoral neck is superior to a femoral head prosthesis.

The patient has done extremely well Another patient with radiation necrosis of the femoral head and pathological fracture had a good result after prosthetic replacement.

4 *Poor reduction of fracture, that is inability to* obtain locking and impaction of the fracture fragments with the femoral head in slight valgus position. One can anticipate a poor result in most cases of this type. This group of patients probably *constitutes the largest to be considered for prosthetic* replacement.

A.

B.

Fig. 239. Fracture of left hip suspected of being pathological because of metastatic lesions in the right ischium, from carcinoma of the breast A, At time of fracture. B, Twenty-two months after insertion of Moore prosthesis, showing very satisfactory condition of the hip The fracture did not prove to be due to metastasis. The patient walks with a cane, has no pain, and has only minimal limp in this hip. *Metastatic* carcinoma in the right ischium is slowly increasing in size. Symptoms are being controlled with hormonal and x-ray therapy

5. Fracture through the neck if the angle of the fracture is such that it tends to be vertical (Pauwel's type 3)

6. Fracture that has undergone considerable delay from the time of occurrence until the time of definitive treatment. Such a fracture does less well than those treated within a day or two of the accident, and prosthetic replacement should be considered in such cases. During the interval of delay between fracture and fixation, absorption occurs at the fracture site, and changes often result from pressure of the sharp neck against the softer head fragment. Fibrosis also occurs about the fracture and capsule, making reduction difficult. Frequently splinting and traction have been relatively poor during this interval. Therefore, a delay of several days from the time of fracture to the time of fixation may be an indication for replacement of the femoral head.

7. Fracture that "falls apart" after reduction and nailing. This type of fracture may be treated best with prosthetic replacement, although some other procedure, such as use of a bone graft, may be preferable at times.

8. Likelihood that the patient will be able to walk again. Very elderly people who are feeble, patients who have had severe strokes that render them unable to walk, and others in similar condition will not profit from this operation. Successful reduction and internal fixation with a Smith Petersen nail, for example, will allow a patient to be out of bed the following day—a bed-chair existence. If the patient is physically able, of course, she can be taught to walk on crutches without weight bearing. Therefore, unless there is some indication for immediate, postoperative weight-bearing ambulation, there seems to be no indication for the use of replacement prosthesis as opposed to internal fixation of the fracture. After a hip has been nailed, the activity incident to moving about in bed without pain or getting out of bed into a chair is adequate to prevent the complications common among patients in the older age group.

9. Age of patient. The relationship of age to this problem is important. Age must be weighed with many other factors, including the indications mentioned previously. It is of interest that the average age of the thirty patients in the present series, in whom a prosthesis was used for fresh fracture, was 75½ years. Of course one evaluates the "physiological" age of the patient as accurately as possible and uses that rather than the chronological age as a guide in deciding whether to use a prosthesis.

PREOPERATIVE AND POSTOPERATIVE MANAGEMENT

As in any fracture, proper splinting at the femoral neck fracture is imperative. It ma the difference between a fracture that can be by conventional fixation methods and one th be treated with a femoral head prosthesis. applied as soon as possible, during transp and while in the hospital bed, is also imper prevent motion and structural changes at of fracture.

No older patient should be put flat on h in bed, but should always be sat up at an at least 45 degrees in bed day and night effort should be made to avoid the complica the aged that will be mentioned later. A evaluation is necessary preoperatively but not be intensive, for a fractured hip in an ol son is at least a semiemergency and sh treated as such. Proper cardiac, renal, and evaluations however are most helpful, e in the immediate postoperative managemen patient.

It is well to have a thorough discussion v relatives before operation so that the possible and local complications will be better unders them.

After insertion of a femoral head prosthe elderly patient with a fractured femoral n patient is returned to bed in a suspended s the Hodgen or Thomas type. As mentioned, tient is put in a semisitting position and an i program to prevent postoperative complica instituted. So far as specific postoperative ca tive to the operation for insertion of the pr is concerned, I feel that these patients are mo fortable with about 8 pounds of adhesive or rubber traction on the limb in the suspendec If the patient will not or cannot move about by using the overhead trapeze, a prop un well foot, and the help of the nursing staff, t splint and traction are eliminated and the is treated exactly as if nailing had been namely sat out of bed daily and turned from side in bed. Active exercise is encouraged. minimal weight bearing on the extremity wh been operated upon is discouraged for three unless walking is imperative for the patient eral well being and cannot be accomplished v more than this minimal weight bearing. Th thesis sets itself more firmly if weight bea avoided for a time and the surrounding bo

portion the prosthesis is less likely to suffer from necrosis, with loosening of the prosthesis.

SURGICAL TECHNIQUE

The first two femoral head prostheses that we inserted at the Mayo Clinic for fresh fractures were of the Judet Vitallium type and the Smith Petersen iliofemoral incision was used. All subsequent prostheses have been of the Moore type and have been inserted through the Gibson approach. On a few occasions the McFarland-Osborne modification was used. Two prostheses were also inserted through this incision, modified by removing the greater trochanter and then nailing it back in place. While there seems to be some criticism of the Gibson approach it has worked most satisfactorily for us. I feel that it should be followed rather completely if one wishes free access to the acetabulum with good exposure. It can be modified by leaving the posterior attachment of the gluteus medius intact and dislocating the hip anterior to these fibers, much as described by Watson Jones, if the acetabulum need not be well exposed.

The critics of the Gibson approach assert that a limp from gluteal weakness is inevitable after this exposure. The limp does not seem to occur if the patient is properly motivated and physically able to carry out an exercise program postoperatively Observation of one very important point in the technique however appears to contribute to a good result. As in tendon transference operations reapproximation of the tendon under tension seems to give a stronger functioning muscle. The tendon of the gluteus medius, therefore is pulled farther distally than the site of its normal insertion and is sutured under tension at the base of the greater trochanter This is done by putting holes through the bone at this point and using mattress sutures of No. 2-0 chromic catgut Posteriorly the tendon must be reattached to the bone in this manner but as one moves anteriorly along the side of the femoral shaft it can sometimes be sutured into the firm fibrous origin of the vastus lateralis muscle. The posterior portion of the gluteus medius muscle is the most tendinous portion, and this is the part that should be very carefully sutured. If this is done and if exercises are carried out postoperatively there should not be any muscle weakness. During closure of the wound the gluteus minimus has already been pulled distally and sutured to the original attachment of the gluteus medius the gluteus maximus is reattached to the fascia lata (Fig 240)

Other helpful points in the technique of operation include the use of a muscle relaxant, such as

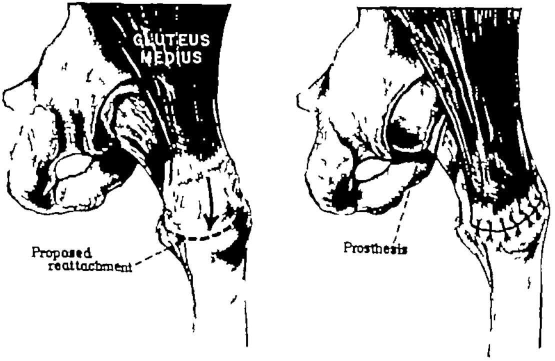

Fig. 240. Reattachment of gluteus medius tendon more distally under moderate tension during the closure of the hip subsequent to Gibson approach.

succinylcholine given prior to dislocating the hip. This allows the procedure to be accomplished with a minimum of trauma and strain on the soft parts.

Although speed is surgery's least important facet today, in older patients who represent increased risk the operation should be accomplished as rapidly as careful technique will permit.

Care must be taken to cut off the femoral neck in such a manner that the calcar and the supporting flange of the prosthesis fit in apposition. Most of the weight is borne at this point, and the more carefully the opposing surfaces are fitted, the less the settling of the prosthesis and the less the chance of loosening. As in all prosthetic insertions, proper length of the structures between the acetabulum and the base of the femoral neck should be maintained. If the neck is too long, the hip will be tight and painful. If the neck is too short, there will be decrease in the lever arm and more inclination to gluteal limp.

COMPLICATIONS

There have been no unusual complications in the present series of thirty patients and no complications different from those in a larger over-all series, except as related to the age of the patients. There have been no dislocations in the thirty patients and no fractures of the shaft or femoral neck distal to the femoral prosthesis, nor has there been gross loosening or intrapelvic migration. It is granted, of course, that these patients put less weight on their prostheses and are in general less muscular and active than the average patient in whom femoral head replacement is carried out.

Patients in whom this procedure is used, however, do form a selective group because of their age and usual debility. Certain complications are more likely to develop (Table 33).

Table 33. Anticipated Postoperative Complications

1	Infection of wound
	Decubiti
3	Mental confusion
4	Pneumonia
5	Infection, lower part of urinary tract
6	Peroneal palsy
7	Death

Operative infection might seem to be more common in this age group. Infection of the wound did, in fact, develop in two patients. In one it cleared up completely without any residual; the other patient was a 93-year-old woman who died of pneumonia on the thirteenth day after operation.

Decubiti are a constant problem, and early and frequent movement of the patient either in bed or out of bed in a chair should be stressed. This obviously requires adequate nursing care, which means the difference between survival and death for many patients in this age group. These patients cannot be put flat on their back in bed after operation with just average nursing care and expected to survive. In this respect, use of narcotics and sedatives should be strictly limited. It seems preferable to allow the patient to be mildly agitated so that she will move about and tend to prevent static complications. Frequent back rubs, frequent changes of position, proper padding, and good nutrition are all mandatory.

Mental confusion is a common complication in this age group. Early operation tends to prevent this. Maintenance of the patient in a partial sitting position in bed day and night, getting the patient out of bed into a chair often, frequent turning of the patient, frequent visits by nursing personnel and relatives, and occupational therapy when possible—all these measures help prevent mental confusion. Soporifics should be avoided or used very sparingly as they add to mental confusion.

Other static problems such as pneumonia and infection of the lower part of the urinary tract must be guarded against. A specific problem that involved two of the patients in the present series was falling out of bed, in spite of all normal precautions. Restraining side rails are always used at night, but patients can climb over these. Undue restraints tend to agitate the patient. There is probably no real preventive of this complication except constant supervision by nursing personnel.

Serious infections of the lower part of the urinary tract can be avoided by the use of an indwelling catheter and urinary antiseptics.

Peroneal palsy may develop in this group, as it does in other patients in traction, and must be carefully watched for. One patient in the present series had peroneal palsy on the affected side, but this cleared up in several weeks.

Death is naturally the most severe complication in this group of patients. It occurred in six of twenty-five traced patients within one year of their fracture.

Dislocation, loosening of the prosthesis, and intrapelvic protrusion could all occur in this group of fresh fractures, but have not, in part because the

activities of these patients are limited and only a few years have elapsed since their prosthetic replacements.

RESULTS

The statistical summary of the results in this series of patients covers the years 1952 through 1956. As mentioned, the series consisted of patients in whom prostheses were inserted for fresh fractures of the femoral neck. The patient was considered to have a fresh fracture if replacement was performed within forty days following the fracture. There were three operations in 1952, seven in 1953, three in 1954, nine in 1955, and eight in 1956. About the same total number of fractures of the femoral neck were seen yearly during this time.

All except one of the thirty patients were women. The youngest was 53 years old. This patient incurred a fracture of the femoral neck subsequent to cup arthroplasty. A femoral head prosthesis was inserted. The oldest patient was 93 years old. The average age was 75¼ years.

The types of fracture which lent themselves to replacement with a femoral head prosthesis were as follows. Ten fractures were subcapital, and for some one of the reasons itemized earlier in this paper it was thought best to treat them with a femoral head prosthesis. Six were transcervical and were treated with femoral head prostheses for the same reasons. One patient had a split of the femoral head along with fracture of the neck. One patient had a fracture of the femoral neck together with a dislocation of the femoral head. Two patients had fractures in the presence of malignant disease in the pelvis: one of these had metastasis from carcinoma of the breast, while the other had a lymphosarcoma of the intestine (ileum). Three patients had an unsatisfactory position of the head after nailing and were therefore treated by femoral head prosthesis nineteen, twenty-three, and twenty-seven days, respectively, after the unsatisfactory nailing. These nailings were technically imperfect, resulting in improper position of the head-neck relationship or improper placing of the nail. Five patients were treated with a femoral head prosthesis at least partly because of a delay between the time of fracture and the time the patient was operated upon. The delay had existed for a variety of reasons, medical or neurological, and as mentioned previously, probably did tend to prevent a good result from nailing.

Of the thirty patients, twenty-five were traced for at least one year following their fracture and operation (Table 34). Ten of these twenty-five patients have died. Six of the deaths occurred within a year after the fracture, and four occurred one to four years later. Only one of the six patients who died within a year walked after insertion of the femoral head prosthesis. Of the remaining fifteen traced patients who are living, five walk without a cane or crutch and are able to get about and do their regular work. They deny much pain. Five walk with the use of a cane and are able to be as active as they wish with this support. Three must use one crutch and are rather inactive at home. Two are unable to walk at all but can stand and help themselves from a wheel chair to a bed and back again.

Table 34. Results of Prosthetic Replacement in Twenty-Five Traced Patients

Dead		10
Within 1 yr	6	
After 1 to 4 yr	4	
Alive		15
No cane or crutch	5	
One cane	5	
One crutch	3	
Unable to walk	2	
Total		25

SUMMARY AND CONCLUSIONS

Femoral head prosthesis seems to be indicated in certain rather select patients who have fresh fractures of the femoral neck. The specific indications for the use of such a prosthesis are still not clear-cut. Continuance of an attitude of conservatism regarding selection of patients for this operation seems warranted at this time.

It can be said, however, that if the patient is not expected to walk again because of senility, neuromuscular disturbances, or general medical condition, there seems to be no indication for use of the femoral head prosthesis. It can also be said that healing of a femoral neck fracture in good position gives a better result than replacement of the femoral head with a prosthesis. Further reports on series of patients must be studied before it can be known which patients can best be served by this procedure. The experience reported here indicates that the results to be expected include the very best and the very worst. Recent examination of a 77 year-old patient who had had a femoral head replacement for a fresh fracture of the femoral neck five years previously revealed that she walks without a cane

or crutch, does all her own housework, shops, has no pain, and has only a slight limp. Her condition has not deteriorated in these five years. No one would deny that this is a good if not an excellent, result. In contrast, a 93-year-old patient died of senility and bronchopneumonia on the thirteenth day after replacement of the femoral head.

There is no need to make a strident plea for or against the procedure of replacing the femoral head with a prosthesis in fresh fractures in the elderly. There is no apparent reason to draw a rigid line regarding this issue, with each of us on one or the other side. Let us recognize the procedure for what it is namely a marvelous method of salvage to be made available to certain patients with fractured hips. While the prosthesis usually gives less than a perfect result, it generally gives more than a poor result.

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PROSTHESIS INDICATIONS IN FRESH FRACTURES AND BASIC CONSIDERATIONS AFFECTING CHOICE OF A PROSTHESIS

INDICATIONS

It is wise to state, as a cardinal rule that the use of a prosthesis in fresh fractures of the hip is contraindicated except in special instances. It should always be the endeavor of the surgeon to nail or internally fix a fractured neck of the femur in order to obtain a viable femoral head. A metal femoral head, though a boon in some cases, is never as satisfactory as a live bony one in which the fracture has been healed and which has not undergone aseptic necrosis. The fact that such an ideal state might be a little difficult to obtain even with the exercise of some skill, some patience, and after the passage of some time and the outlay of some money should not influence the surgeon in his judgment as to which procedure is indicated. The statement "a live head is better than a dead one" is not a platitude, but is made with the full realization that, even with the best of care 20 per cent of fractured necks of the femur usually result in nonunion and that another 20 per cent usually develop varying degrees of aseptic necrosis. Only half of these aseptic necroses, however will lead to further surgery because of the pain. In other words, if one accepts the belief that 65 per cent of nailed, displaced, fractured necks of the femur are generally satisfactory to the patient, it is therefore better to routinely adopt the policy of internal fixation than to be gulled into the immediate use of a prosthesis.

Basically what are the arguments for and against the use of a prosthesis in fresh hip fractures? There are three main reasons why a prosthesis is advocated by most people (1). The first is an economic reason. It saves the patient money by reducing the long hospitalization otherwise required. (2). Second, it allows for early ambulation. Most of the elderly patients are able to get up and walk within a few days and to be home in a very short period of time. (3) Third, it does away with the problem of nonunion, with its threat of a secondary salvage operation in which a prosthesis is usually inserted.

These are three very potent arguments. They form a basis for the reasoning to justify the procedure in those special instances wherein we all agree that the prosthesis is indicated. The fact that the best prosthetic end results are obtained in this fresh fracture group rather than in the salvage group should not be used as a *fourth* reason to advocate its early use.

Most surgeons, for their own hips, would rather have a living, healed fractured head than a metal prosthesis. Not all prostheses are painless, and some do cause considerable trouble. I do not know the percentage of painful hips following the use of prostheses in fresh fractures, since my judgment has been to nail all fractures when possible rather than to use a prosthesis—which I have used, almost totally as a salvage procedure In many such instances of

salvage it has been necessary to perform an arthroplasty of the acetabulum, with the reaming out of a new socket before insertion of the prosthesis. Certainly not all of these operations result in perfect hips. By comparison with a nailed and healed fracture they fall far short of an ideal. In the five year follow-up of patients having a prosthesis for salvage, there are only two hips which I think are absolutely perfect, without limp and without pain or need for a cane, whereas roughly 70 per cent of the solidly healed nailed hips are perfect after five years, without limp or cane. This is a figure to make one stop and ponder. It tends to put into the background the economic factor of a little money saved or the nicety of allowing early ambulation. There may always be that 20 per cent incidence of nonunion to darken the picture but this should be a challenge to us to attain a better reduction at the time of operation and to immobilize our patients longer without ambulation until union has occurred.

Is there any situation in which the surgeon is positive that union cannot be attained by the standard nailing procedure? There come to mind the dead head of overradiation and the three P's—Porosis, Paget's disease, and Parkinson's disease.

The constant movement of *Parkinson's disease* usually works the nail out of the head and thus has resulted in a very high incidence of nonunion. If this mechanical factor is obliterated, however, by the use of a plate attached to the nail laterally or by the use of a telescoping nail, the nail extrusion can be prevented.

In *severe osteoporosis* the slow healing and almost total lack of periosteal new bone formation have caused delayed union. This osteoporotic group certainly should not be allowed to ambulate early. Union, however, may be achieved with internal fixation, the correction of the negative calcium balance and the passage of sufficient time. There are some special instances in which the femoral head is so soft that the Smith-Petersen nail can be pushed into the head with the finger instead of being driven home with the hammer. These cases, which will result in mechanical failure, represent special instances in which the immediate use of a prosthesis is justifiable. Most osteoporosis, however, is not so severe and does not constitute an occasion for the use of a prosthesis.

In Paget's disease likewise fractured femoral necks take a long time to heal. In this particular disease, a prosthesis is probably contraindicated since a limited practical experience has demonstrated that the shafts usually melt away beneath the prosthesis. With any mode of treatment it is difficult to achieve a satisfactory result, but nailing is *preferable here to* use of a prosthesis.

The three P's, therefore, although they form a group in which nonunion is common, do not represent a situation in which union cannot be attained by the standard nailing procedure. It is the other factors present in these individual patients that add up to the special indications to justify the immediate use of a prosthesis.

The *dead heads* that result from excessive use of radium or roentgen therapy are rarely seen nowadays, but this situation constitutes the best special indication for the immediate use of a prosthesis. In these individuals the bone is dead and normal healing is very much in doubt. This dead head group is probably the only group in whom union cannot be achieved by the standard nailing procedure. In the others, union can be achieved if the surgeon not only is competent but also has patience.

There are other justifiable indications or special instances in addition to the ones described above. These may be listed as

1. Fracture occurring in a head with aseptic necrosis.
2. Fracture in metastatic tumors.
3. Primary cystic or malignant bone disease, as a humane adjunct to nursing care.
4. Fractures occurring in severe chronic, multiple rheumatoid arthritis.
5. Fractures occurring in the course of shock therapy in mental patients for whom the treatment needs to be continued.
6. Fractures in spastic hemiplegia.
7. Fractures in the aged totally blind, because of their inability to use crutches in the convalescent period.
8. Fractures in hips deformed because of severe osteoarthritis.
9. Failures to obtain any bony contact at the time of the operative reduction.

Age alone is not an indication but, taken in conjunction with other considerations, it may be part of a picture that forms a special indication.

These special instances justifying the immediate use of a prosthesis have been described before and in my opinion represent valid reasons. The total *group of indications*, however, should comprise less than 10 per cent of a surgeon's practice dealing with fractured necks of femurs.

If one is going to use a prosthesis, either for fresh fractures or for salvage the choice of the type of prosthesis may depend upon the local situation present in that patient's hip. Some surgeons still prefer the Judet design although now they constantly use metal prostheses rather than ones made of acrylic or nylon. Most surgeons, however believe that although these prostheses unquestionably work in some instances, it is preferable to employ the intramedullary stem type. It seems wise therefore, at this point to review some of the controversial ideas and the principles of an intramedullary stem prosthesis and to relate some of the experience we have gained during the past eight years of their use.

CHOICE OF PROSTHESIS

Metal. It seems unnecessary at this stage of our knowledge of metals used in orthopaedic surgery to mention the fact that Vitallium, up to the present time, has proved superior to the use of steel or other metals or plastics. Not only is Vitallium a satisfactory metal, but the company producing the appliances is using more than ordinary skill, care, and know-how to produce a dependable product. The head of the prosthesis can be counted upon to be perfectly spherical which is not always the case with some steel appliances we have tested. The hollow head of the Vitallium appliance is airtight and does not allow fluid or other material to get into the interior of the sphere during the process of autoclaving and sterilization. Thus has not been found to be the case with certain steel prostheses. The hardness of Vitallium helps it resist the wear of friction considerably better than does steel. Erosion within the body has not been encountered. In operating upon these hips at later dates, there are none of the grayish particles found that are seen in the tissues of the synovium and cartilage following the use of steel. In none of the patients operated upon, who possessed a Vitallium prosthesis, have I found the chronic villinodular synovitis that has been seen in some painful hips due to a steel prosthesis. (Fig. 241.) Although I have been unsuccessful in producing this villinodular synovitis in experimental animals with the same metal that causes it in the human patients, there is no doubt that it occurs in the human being with steel that was thought by its manufacturer to be perfectly safe and adequate for use within the human body.

Since there are no great objections to Vitallium from other standpoints, it would seem wiser to use it rather than steel, because of these many factors.

Fig. 241. Painful chronic villinodular synovitis eroding through the lateral femoral cortex at several areas in the shaft and in the acetabulum. Removal of the steel prosthesis cleared up the synovitis. No infection or malignancy was present.

The author has never permitted his prosthesis to be made by any but one firm. Steel prostheses of his type are poor copies of the original. It is unfortunate not to be able legally to prevent these copies from being manufactured and sold under tricky advertising such as "Thompson Type Prosthesis."

Shape. The employment of the many different shapes of prostheses is welcomed because of the information they yield to the profession. Out of our experience will come a slow consolidation of opinion as to which is the better size, shape conformation, and design. Many of these prostheses have been changed from their original shape to conform to certain principles demonstrated as superior in other prostheses. The Eicher prosthesis is a case in point. It has had a change in the stem shape and in the

Fig. 242. Three and one-half years after prosthesis insertion for fresh fracture. There is minimal stem motion and telescoping. Greater trochanter has decalcified. Joint space is not so wide as after the first year of use.

collar It is now made from Vitallium instead of only from steel. The Thompson has been changed in the stem. (Fig 242.)

Stem In considering the intramedullary prostheses, agreement has not been reached on certain principles of their shape and size. We are not sure of the best length for the intramedullary stem. We know the stem must be massive enough to resist breakage and we have found from experience that breakage has not occurred at the junction of the stem and the collar as originally anticipated from an engineering standpoint. It has occurred in most instances, within the terminal two inches of the stem tip. Making the stem thicker near the tip will probably solve this problem. Massiveness is not contraindicated in a prosthesis, since the patient is not aware of this extra weight nor is it—or enlargement in stem size—detrimental to the marrow cavity The only point to be considered in a thicker stem is the relative difficulty of introducing it into the medullary canal in younger people. There is nearly always room *within the canal in older people. If a thicker stem is* used it may need to be curved and shaped somewhat to fit the slight tortuosity present within the cavity (Fig 243.) This is already engineered into the right and left Thompson protheses.

The stem of some styles of prostheses is manufactured as a unit separate from the head and neck of the prosthesis. It is believed advisable, when possible not to have moving parts, lest friction then occur and produce fatigue breakage. This disadvantage must be offset and balanced against the fact that changed local conditions at the site of the fracture may make the use of a multipart prosthesis more advisable in a particular instance. It is wise to continue the use of this style of prosthesis, to give us information for the future and to help us to arrive at a broader general knowledge.

The thick, round prosthetic stem, as originally devised by me, provokes a very favorable response of the bone even after seven years of continuous use (Fig 244) It completely fills the intramedullary cavity in the area and is encased by dense cortical type of bone. There is perhaps only the mildest amount of motion to allow for the elastic movement of the shaft. There is some question in my mind as to whether perhaps the thick, round stem might not be as good as or better than the existing thinner stem of my prosthesis. The round stem however is more difficult to insert, and if the present triangular shape is as strong and breakage does not occur it is better to leave the stem as it is now There is no doubt that

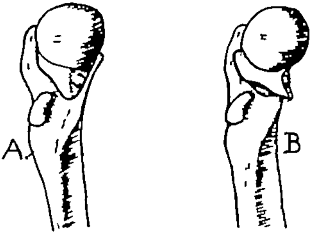


Fig 243. Medial aspect of the upper end of left femur showing how the curved stem of a left 1¾ inch prosthesis seats the collar correctly in A, but how it turns, anterior to the calcar in an improper seating (as in B) in some cases when straight stem is used.

Fig 244. Seven years after insertion of earlier round stem type of prosthesis. Note favorable response of the shaft to the stem. The cortical shell surrounding the stem began at the stem tip and progressed upward to collar. Motion of stem in the shell was never noted, either sidewise toggle motion or telescoping. Greater trochanter has lost most of tension trabeculae.

the present thin stem is easier to introduce into all types of people.

Collar A second consideration is the angle that the collar subtends to the stem (Fig 245) The Moore and the Eicher prostheses are more nearly transverse than the Thompson. This more transverse position is preferred by the draftboard engineers to serve as a platform for receiving compression stress forces. From a practical standpoint, however more of the calcar and neck of a femur needs to be present in the bone on which this platform rests than is necessary with the more acutely angled neck of the Thompson prosthesis. This extra amount of femoral neck and calcar unfortunately is not always present in some neck fractures. When it is present these prostheses are excellent to use. It is doubtful whether the very wide collar of the Eicher prosthesis is necessary. Actually it might be symptom producing in that it rests against the psoas tendon and the sides of the synovial membrane and capsule for it juts well beyond the cortex of the femur at that level. (Fig 246.) Experience has demonstrated that the weight of the body can be sustained on the calcar alone. The cortical bone of the anterior and posterior aspects of the bone of the femoral neck and the trochanteric bone laterally are so fragile that they play no practical role in sustaining the body weight. When the femoral head and neck have been removed the density of the bone trabeculae in the greater trochanter diminishes because the tension trabeculae normally present there in the bone disappear (Fig 247.) Only the compression trabeculae remain and thicken. This hypertrophy of the compression trabeculae occurs chiefly in the region of the calcar as everyone notes in roentgenograms subsequent to the insertion of a prosthesis. The projecting lip of the prosthesis therefore needs merely to cover or extend very slightly beyond the medial cortical bone margin of the calcar to be satisfactory.

In salvage use of the prosthesis (Fig 248) where there has been complete absorption of the neck of the femur there is not sufficient calcar present to use the more transverse-angled style prosthesis unless the posterior part of the prosthesis collar is sunk well into the greater trochanter (Fig 246) This is likely to cause an expansion of the greater trochanteric region which can produce pain as the prosthesis settles somewhat in the months following operation. Similarly when a prosthesis is too small for the patient's bone, so that it tends to sink inside the medullary cavity instead of overlapping the calcar pain is produced by the expansion of the bone until the settling has occurred to such an extent that the collar actually erodes somewhat through the medial cortex and comes to lie on top of the calcar trabeculae at a lower level than originally intended. (Fig 249.) This has happened in certain instances in the past where the available prosthesis used was too small and had been placed in the large femur of a Nordic giant (Fig 250)

When a lot of femoral neck is preserved medially at the site of the calcar it is more difficult to insert the prosthesis than when more of the neck is cut off to a point about 1 cm. above the level of the lesser trochanter

The passage of time will demonstrate which is the better angle for the collar to subtend to the stem of the prosthesis.

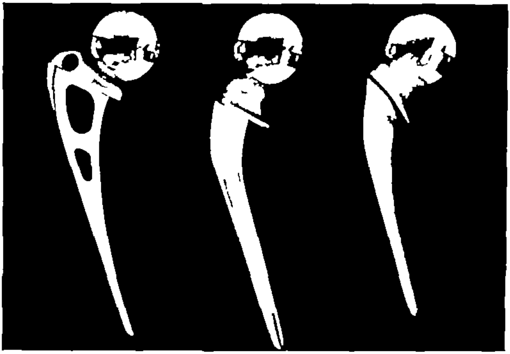


Fig 245. Photographs of Moore Eicher and Thompson prostheses mad of Vitallium. Note the different angle the collar subtends to the stem.

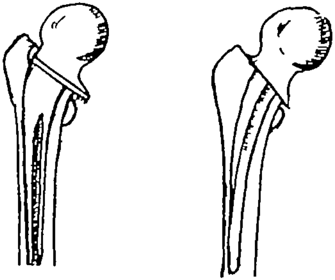


Fig 246. When not enough calcar is present, the more horizontal collar type of prosthesis must be countersunk deeper into the greater trochanteric region

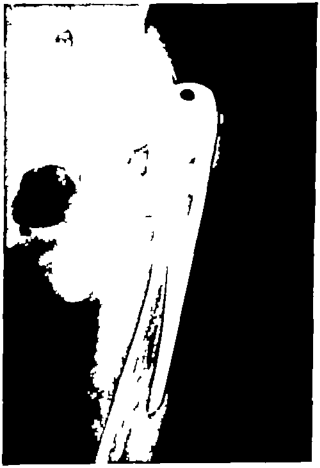


Fig. 247 Moore fenestrated stem prosthesis Note toggle motion of the stem. Th pain in this patient is due to arthritis on the acetabula side of the joint and not to stem motion.

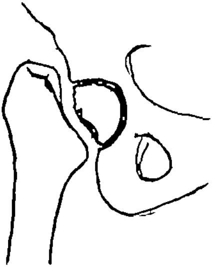


Fig. 248. Tracing of a nonunion of the neck of the femur showing absence of femoral neck in some instances of I tended salvage. Many fractured necks tend to absorb down to this basic level for some unknown reason.

Fig. 249. Too small a prosthesis has been pla ed inside this bone so the collar f lled to *overlap the calc* As it settled inside the neck t produced symptoms ntil enough of the calcar finally sustained sufficient weight Note small toggle motion of the stem No telescoping was present.

Fig 250. Wide swing of the stem severe osteoporosis, causing expansion of posterolateral shaft cortex The patient walked with one crutch and had minimal ymptoms of pain but no local tenderness. Too small prosthesis was placed the shaft of a large bone

Fenestrations. Fenestrations in the stem of the intramedullary prosthesis were devised with the idea that motion within the shaft could thus be more surely obliterated Practical experience, however has shown us that all stems will develop a certain amount of play or movement within the intramedullary shaft, if the person is active. (Fig 247) Stems that have become immobile by means of the bone growing apparently securely about them or through them have later loosened. This is due to the fact that the modulus of elasticity of bone is different from that of the metal employed in the prosthesis. (Figs. 242 and 249) Bone constantly bends and arches to some slight degree with body movements. If the metal did not bend too or move within its bony encasement, fatigue fracture would occur It is fortunate that nature allows slight movement to occur between the stem and the side wall of the shell made by the bone to encase the stem. This slight motion takes up the slack necessary to compensate for the elastic movement of the bone. (Fig 242.) Where a wider movement of the stem has occurred within the shaft, such as in older people with a wide intramedullary cavity or in osteoporotic bone, it is not usual for this wide swing of the stem to be symptom producing Bone tenderness is not noted laterally In some instances the lateral cortex has been found to be actually expanded somewhat by the pressure of this swing of the stem. A marked swing in a patient with severe osteoporosis is noted in Fig 250 Motion be-

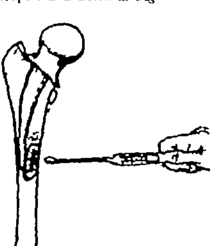


Fig. 251 To immobilize the stem of the prosthesis, bone bits are packed into an anterior window made by enlarging a curett hole in bone with successively larger curettes. Retracting the distal end of a anterior ski incision makes this quickly possible in some decalcified bones at the time of salv ge operation

yond the normal can occur in the fenestrate prosthesis as well as in the solid stem typ fenestrations are placed close to the fulcrum seesaw movement. Blockage of the swing of t to prevent this seesaw movement is better plished by wedging bone into the femoral sha the tip of the prosthesis (Fig 251) The fe easily entered near the tip of the stem by curette and the window enlarged by larger c and it is possible to firmly pack iliac b an immobilizing manner about the stem o prostheses. It is easily done when an anter cision is used, by retracting the lower end of cision.

It is a mistake to think of the stem of th thesis as a "self locking appliance." Such a phrase is misleading Although bone packed i fenestrations of the stem near the upper end femur will encourage early temporary immo tion of the prosthesis, this is not permanent 247) Most of this bone later absorbs in su degree to allow varying amounts of stem swin disadvantage of using fenestrations in the that it makes subsequent removal of the pro if necessary an extremely difficult procedure. wide medullary canals of older people howeve comforting to pack bone into these fenestratio hope that an early anchorage will be obtain the solid stem prosthesis this same early anch when desired, can be obtained more secur packing bone about the stem tip (Fig 251)

Where a small collar is used that is just su to properly cover the dense bone of the calca mobilization of the prosthesis is enhanced by growth of bone lipping around the edges collar Such prostheses when seen at subs operation, do not telescope or seem to mov preciably within the bone at that point. Sligh wise movement of the stem, however is bou occur at a lower level.

Head of Prosthesis It is not so simple a p as one might imagine to select the correct s the femoral head. In the beginning we believe the fit between the normal cartilage of the ac lum and the metal head had to be as exact a sible. We have found from experience however nature fortunately makes the acetabulum later itself to fit the metal head. If a smaller head is the articular cartilage will grow outward to surfaces of the metal head and the actual aceta socket size will be narrowed by this overgrown cartilage. Similarly the use of too large a hea

erode certain areas of the acetabulum in an attempt to make the fit more perfect. Too large a head, however, can subluxate more easily than a smaller head. In general, in fresh fractures it is better to select a head the size of the natural one removed. But if one must err, it is better to err on the side of a slightly smaller metal head (Fig 242) In salvage use also, where a reaming out arthroplasty of the acetabular cartilage is performed, it is always wise to choose a small head and to use a small reamer in keeping with this small head size. Practical experience has demonstrated that the body weight can be sustained on a smaller head than nature originally intended for that individual. When reaming out and deepening a socket at a slightly higher level than the original one there is not much room to make a larger socket in the triangular space formed by the cortical iliac walls of that area.

Right and Left Prostheses The use of a right and a left prosthesis is sometimes important. In younger individuals where the intramedullary cavity is narrow it is sometimes almost impossible to insert a straight stem prosthesis. The curve built into a right and left stem, however makes insertion very easy This is particularly noticeable in small, middle-aged people of South American or Latin extraction. There is present in the right and left prosthesis a posterior twist of the head and collar on the stem itself amounting to about 40 degrees. This more securely seats the femoral head within the acetabulum than does a straight stem prosthesis. When a straight stem prosthesis is used, the head tends to assume an anteverted position of sometimes over 60 degrees, and frequently the collar of the stem does not properly overlie the calcar but lies anterior to it on a softer area of cortical bone (Fig 243) It is believed that some people walk better with the lessened anteversion afforded by a properly shaped stem than they do with a straight stem. From a manufacturing standpoint, it would be advantageous to have a straight stem which could be used on either the right or the left side. Unfortunately it is not always wise to use one but there are certainly many instances when no appreciable difference can be noted. This is a point that will be clarified by the passage of time and by careful observation of many cases.

CHOICE OF INCISION

The choice of incision is very much up to the operating surgeon I now prefer an anterior incision in most instances of salvage operation, since it is difficult in many to determine preoperatively whether or not the reaming out of articular cartilage or arthroplasty of the acetabulum will be necessary In fresh fractures, where this is not a problem a posterior incision is equally as good as an anterior one The loss of blood in both operations, need not be more with one incision than the other From the anesthetist's standpoint, an anterior approach is preferable. A posterior incision is an anatomist's delight in getting into the area. The division of muscle insertion in the posterior incision hinders early ambulation whereas after an anterior incision ambulation in cases of fresh fractures may be started the day following surgery Advocates of the posterior incision feel that there is less danger of subluxation of the prosthesis from the acetabulum than with suture of the capsule through the anterior incision. Plaster boot immobilization following surgery should not be necessary after either incision if the capsule is properly sutured. Boots are sometimes necessary however after salvage operation arthroplasties.

CAUSE OF PAIN

The causes of pain after use of some prostheses are still not definitely determined. In some instances, where the roentgenograms appear to be satisfactory and the response of both the shaft of the bone and the acetabulum to the metal seems to be within normal limits, it is difficult to tell whether the pain comes from the shaft side of the hip joint or from the acetabular side. It has been my good fortune to see many such painful hips. Conservative care and patience have allowed many of these to recover spontaneously without surgery It is as though nature had not fully adapted her bone to the metal but at a later date, after further settling and accommodation occur she seems to get used to it. In others, operation has revealed varying pathology including the presence of fragments from acrylic prostheses and the presence of minute friction particles from steel prostheses.

Chronic villonodular synovitis causing erosion of cortical bone in both the shaft and the acetabulum has been seen only in association with steel prostheses (*Fig 241*) This has cleared up spontaneously when the steel has been removed The courage to immediately replace the steel with a Vitallium prosthesis has been lacking, although it may be done later when the punched-out areas in the bone have healed.

Since the synovial membrane of the hip joint extends down to the tip of the prosthesis as well as over the calcar and head, injection of procaine into

the joint has not been helpful in pinpointing the source of the pain. I believe however that in most of these painful cases the pain comes from some pathology on the acetabular side of the joint. In a few too large a prosthetic collar has caused irritation of the synovial membrane or caused a bursitis postero-lateral to the psoas tendon. In the vast majority however there is a very distinct change in the cartilage of the acetabulum. In such instances a removal of the prosthesis, with an arthroplastic reaming out of the socket and the reinsertion of a similar prosthesis, has resulted in relief of pain.

With the widespread use of antibiotics following surgery some infections associated with the original operation are disguised, and many painful hips are in reality persisting low-grade infections which do not show themselves in the early roentgenograms. The proper management of such low-grade infections is not known. Some prefer open drainage, with the use of antibiotics locally as well as parenterally followed by a secondary closure of this wound. Others prefer removal of the metal prosthesis with a salvage Colonna type of procedure being done. A stable hip or even an ankylosis can be obtained by this method. Arthrodesis is out of the question at the time the prosthesis is removed from the infected bone but it may be used later Iproniazid (Marsilid) has been a great help in allowing draining sinuses to close over a Vitallium prosthesis, but such salvage has rarely resulted in a functional joint. Recurrent infections have been the rule resulting ultimately in ankylosed hips of varying degrees.

With the experience gained by operating upon such painful hips and being successful in relieving their pain, there is a growing tendency to operate and explore for the unknown source of pain. Formerly not knowing for what to explore, we did not practice this. It is believed now however that since an intramedullary hip prosthesis is essentially a sound mechanical appliance reoperation may determine and correct the local fault that is causing pain In a prosthesis used for a fresh fracture, the pain is most likely to be a destructive, progressive arthritis of the acetabulum. Pain will not be relieved unless an arthroplasty is performed reaming out the diseased cartilage and forming a new socket to be lined later by a new fibrocartilage

AUSTIN T MOORE M D
Columbia South Carolina

THE MOORE SELF LOCKING VITALLIUM PROSTHESIS IN FRESH FEMORAL NECK FRACTURES

A New Low Posterior Approach (The Southern Exposure)

In 1940 the author with the assistance of Dr Harold R. Bohlman, of Baltimore, inserted the first Vitallium prosthesis to replace the upper end of the femur[1] This was an appliance about twelve inches long It was used in a large patient with pathological fractures, who had been treated for eight years for a giant cell tumor that continued to grow in size and was becoming malignant. Dr Bohlman had experimented in a few previous cases with a stem prosthesis to replace the femoral head. In 1946 the Judet brothers in Paris, Jean and Robert, began to use a stem prosthesis with an acrylic head. The prosthesis was very similar to the original ones used by Bohlman. They soon used these in large numbers and reported their results in 1950. A wave of enthusiasm swept the world and Judet prostheses and other modifications were used by the thousands. It was thought by many that the "unsolved hip problems" had been solved.

The author was unimpressed and refused to use any of these prostheses. He had been thinking of a prosthesis to replace the femoral head, ever since the original prosthesis to replace the upper one third of the femur had been used in 1940. Finally in early 1950 he consulted with Dr Robert L. Sumwalt, then Dean of the School of Engineering and now President of the University of South Carolina, and with Hans Reymann Chief Engineer of Austenal Laboratories in New York City He then devised an intramedullary prosthesis that had a fairly straight, solid stem. This was inserted in a doctor friend who weighed over 250 pounds and was crippled with a nonunited hip fracture. The approach to the hip was made through an anterior Smith Petersen incision. Insertion of the prosthesis was extremely difficult and could be accomplished only after reflecting most of the abductor muscle origin from the crest and side of the ilium. It was realized that this approach was not satisfactory A new low posterior approach was developed and the prosthesis was modified to its present form with a long gently curving stem, fenestrations for bone grafts a collar a fin and a flat undersurface to lie along the calcar femorale.

It was calculated that this prosthesis carried stress of weight bearing in ten different areas, whereas a short stem prosthesis carried practically all of the weight in one area. The writer was of the opinion that if the average body weight of 150 pounds could be divided among ten places, with only 15 pounds each the result might be a stimulating effect on bone formation and an increased density about the prosthesis. On the other hand 150 or more pounds of pressure on one spot could be too much pressure,

resulting in pressure necrosis, absorption of bone, and loosening of the prosthesis. Time seems to have demonstrated this as correct. Stem type prostheses, especially acrylic heads, have broken from years of use.

It is interesting that in the first paper read by the author in November 1951 it was stated concerning stem prostheses "None of them has appealed to the author as being sound enough to support weight without pain and to withstand the stress and strain of active use over a long period of time."*

It was further stated in that same article in which he reported on thirty three cases involving operation during the previous one and one-half years. "The author has for a long time realized that if a prosthesis could be developed that would be easy to apply safe to use and mechanically sound enough to support weight without pain and to withstand the stress and strain of active use over a long period of time it would be superior to any reconstruction operative procedure in vogue today"*

He also stated, in closing that discussion "The ideal prosthesis is one that is dynamic and is so designed that the stress is so distributed that the bone not only tolerates it without breakage but reacts to it constantly by hypertrophy and thickening wherever and whenever necessary to react to the stress that is thrown upon it. In this way figuratively the prosthesis becomes a part of the living bone"*

The author made a second report on seventy five self locking hip prosthesis cases, in 1954[3] In a third article, in 1957 he reported 159 of these operations.

It has now been nineteen years since the first Vitallium replacement operation was performed. It has been nine years since the first prosthesis of the present type was used to replace the femoral head. The author wishes to avoid being unduly enthusi

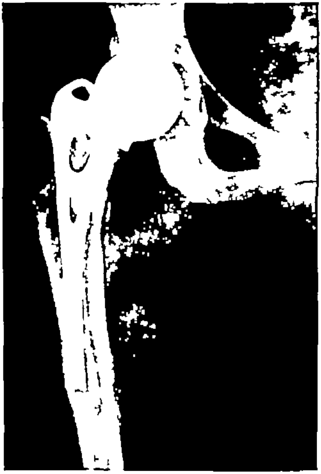


Fig. 232. W H C. 38 years of age. Perfect clinical result six y ars after operation This case beautifully illustrates bone h perplasia that dev lops in the stress-bearing areas. This proved expecially true this young igorous, healthy woma who weighs about 145 pounds. Compare this roentgenogram with the photographs of light weight more inactiv old ladies in F es 233 nd 34

Fig. 233. H Z. Perfect clinical result six years after operation. This illustrates increased density I the stress-bearing areas, within the fenestrations and underneath the prosthesis. Notice that increased density is in the upper portion of fenest tions where stress of weight is borne

From Moore A T Metal Hip Joint A New Self Locking Vitallium Prosthesis South M J 45: 1015 1952.

astic. In the first article in 1951 he stated "End results cannot be evaluated for many years. Enthusiasm in the use of hip prostheses should be restrained until a large number in use over a long time justifies their continuance"[4] What is a large number and what is a long time? Now after nine years, I have 211 patients and 221 operations to report upon (ten being bilateral cases)

Special features and advantages of the self locking hip prosthesis have previously been reported.[1]

Results thus far have justified faith that was placed in the method. Results of this method reported by others have varied from discouragement to avid enthusiasm. In my personal experience early expectations concerning bone reaction about underneath, and through the prosthesis have been fulfilled There have been some beautiful examples of bone hyperplasia in response to stress (Fig 252) At first I was told that it was unsound physiologically to expect that cancellous bone placed in the fenestrations of the prosthesis would grow and harden to take weight-bearing stress and lock the prosthesis in place. Furthermore, it was suggested that the large stem occupied so much space in the medullary cavity that it would interfere with circulation and that pressure necrosis would result. It was my contention that the fenestrations would be helpful in providing channels through which blood vessels could pass. In this way circulation and nourishment to the upper end of the femur would be improved. It has been proved by roentgenograms and microscopic sections that the cancellous bone does undergo hyperplasia and metaplasia and becomes converted to cortical bone in the stress-bearing areas about the prosthesis and in the upper stress-bearing areas of the fenestrations of the prosthesis (Figs. 252 to 255) This is in accord with Wolff's Law that "the internal architecture and external appearance of bone conform to the stress placed upon it." It has been thrilling to observe these changes take place after months or years of waiting Conversely it has been interesting to observe absorptive changes take place as a result of too much stress or as a result of infection. It has been definitely proved that the better the cases are selected, the better the operation is performed and the better the aftercare is carried out, the better is the end result.

Fig. 254 L. S 75 years of age. At the time of operation in 1951 the diagnosis was acute fracture of the femoral neck The loop had been removed from this prosthesis to be sure that the loop would not interfere with abduction of the thigh. This very interesting roentgenogram was made eight years aft operation Motion pictures demonstrat that the clinical result is perfect This patient weighs only 90 pounds nd has never used a crutch or cane. This case pparently proves that the prosthesis is so well designed that it can carry the light load of weight-bearing stress in this patient with very little increased density in bone except at the upper weight-bearing areas.

From Moore A. T Metal Hip Joint. A New Self Locking Vitallium Prosthesis, South. M J 45: 1015 1952

Fig 255. M. F Bilateral prostheses for acute cervical neck fractures one year apart.

TECHNIQUE OF OPERATION—SPECIAL APPROACH: "THE SOUTHERN EXPOSURE"

Details of technique have been previously reported[4] The more I use the special low posterior incision that will be described (Figs. 256 to 260) the more I believe that reiteration of its description is justified. We like this incision so well now that it has been adopted for practically all hip work fusions, arthroplasties congenital dislocations of the hip shelv

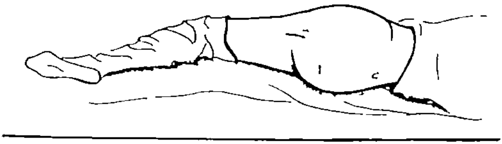
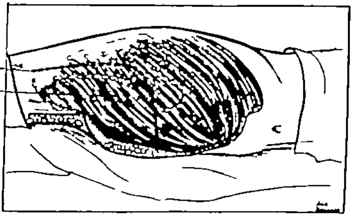
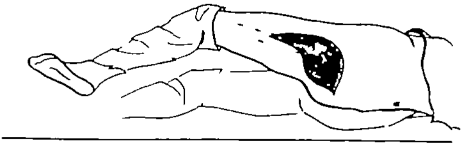


Fig 256.

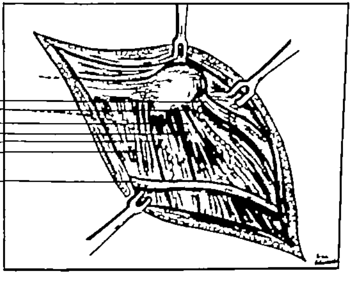


For e posure skin edges are retracted and gluteus maximus fibers are separated by blunt d ssection between bundles 4 and 5



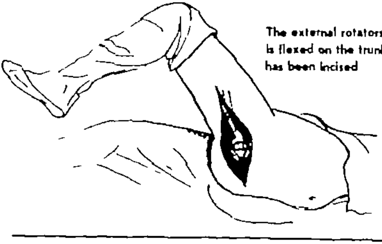
The gluteus maximus f bers have been split longitudinally to e pose

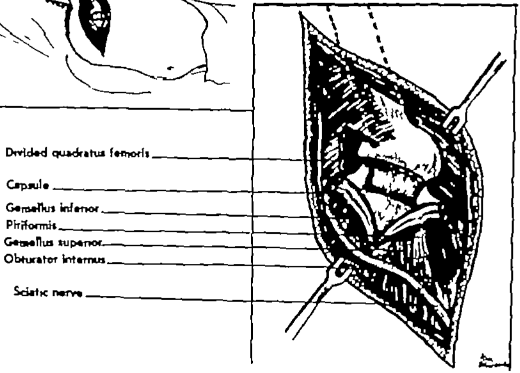
Fig 257



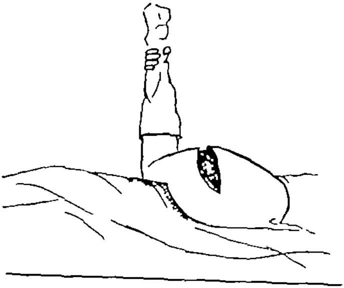
Figs. 256-260. Drawings illustrating progressive steps used in the technique of the southern exposure

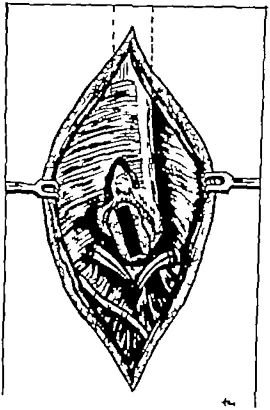
The external rotators have been divided at their insertions The thigh is flexed on the trunk and partially internally rotated The capsule has been incised





Fig





Fig

The thigh is flexed to a right angle internally rotated to 90 degrees and fully adducted The foot points to the ceiling
The slot in the femoral neck is angled 25 degrees toward the posterior portion of the greater trochanter
This preserves normal anteversion of the neck
The patient walks normally with the toe pointed forward

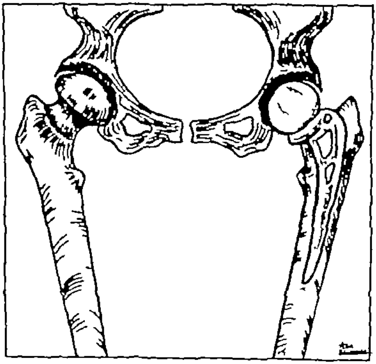


Fig. 260. Technique of the southern exposure (cont'd). The Moore prosthesis can be used in either the right or the left hip. When it is correctly inserted, leg length and anteversion of the femoral neck should be restored. The patient should be able to walk normally with the toe pointed forward. The prosthesis head size should be carefully selected so that it fits the acetabulum accurately. The prosthesis stem should fit tight in the femoral shaft.

ing operations, etc. By stripping muscles, ligaments, and capsule from the femur as is necessary practically any hip operation can be performed more easily, quicker, with less blood loss and with less shock than by any other method. In fresh femoral neck fractures *the operation can be performed in less time and with* less shock than the usual nailing operation. We usually consider that the average case will require about thirty to forty-five minutes. A large number of our patients have been operated on in less time than that—*many in twenty to twenty-five minutes*—and in one instance, in which a special trial for speed was made, the operation was completed, from the time of incision until the last skin suture was placed, in thirteen minutes. Efficiency should not be sacrificed for speed. We insist on precision at the time of surgery and we do not emphasize speed. The simple fact is that the operation is such that it can be done quickly and safely. No large vessels are cut, bleeding is slight, and shock is minimal. No important muscles are divided and there is no reason for a postoperative abductor limp or lurch. No postoperative support is required and the patient may be up and about in a few days on crutches. Leg length in most cases should be equal.

The Low Posterior Approach Compared With the Posterolateral (Gibson) Approach. This is an entirely different operation from the Gibson approach. It has been waggishly called the southern exposure, as the incision is placed over the low part of the buttocks near the south side. *Figs. 256 to 260 illustrate* the technique of the southern exposure, and differences between the two approaches are listed on page 315.

A detailed description of operative technique need *not be repeated. Briefly* the patient lies on the sound side. The incision is begun over the lower portion of the gluteus maximus muscle about four inches below the posterior superior spine of the ilium. It is continued downward and outward below and behind the greater trochanter and down the posterolateral border of the thigh for a distance of four or five inches. The deep fascia is incised and the lower bundle of gluteus maximus fibers is separated upward by blunt dissection with the fingers to the point where the superior gluteal vessels lie. The thigh is flexed to ninety degrees and the gluteus maximus with its fascial extension is easily retracted upward over the greater trochanter. The lower fibers of the muscle are retracted downward and their

Low Posterior Approach (Southern Exposure)	*Posterolateral Approach (Gibson)*
1. Begins about 4 inches *below* the posterior superior spine of the ilium at inferior portion of gluteus maximus muscle. This incision is about 6 inches lower than the Gibson incision.	1a. Begins 2 inches *above* the posterior superior spine of the ilium at superior edge of gluteus maximus muscle
2. Incision extends to a point 2 inches *below* and posterior to the greater trochanter. Extends down back part of thigh	2a. Incision extends to a point *above* and anterior to the greater trochanter. Extends down outer side of thigh.
3. Gluteus maximus is retracted *forward*. Lower aponeurotic fibers at their insertion may be divided to give excellent exposure. Incision 8 to 10 inches.	3a. Gluteus maximus is retracted *backward*. Longer incision necessary, often 12 to 15 inches.
4. Sciatic nerve lies in incision. It is easily *protected* from injury and its sensory branch to the posterior capsule is easily *divided*. This may aid in lessening postoperative pain.	4a. Sciatic nerve is not exposed. It may be *injured*. Its sensory branch to the posterior capsule is *not divided*.
5. Gluteus medius and gluteus minimus are *not divided*. No important muscles are cut. *No* postoperative support is necessary. The patient may be up in a few days. There should be *no limp*	5a. Gluteus medius and gluteus minimus *muscles are cut* from their insertions and retracted upward. A postoperative support is used. Delayed walking and weak abduction of the hip with a *limp may* result.
6. The capsule is incised in its long axis on its *posterior inferior* aspect. Its distal insertion is stripped from the posterior portion of the *base* of the femoral neck. *No ligaments are cut*. The "umbrella" of the capsule holds the head in the socket. *Dislocation* is *scarcely possible*—even under anesthesia.	6a. The capsule is incised in its long axis on its *anterior superior* aspect. The capsule is cut transversely from the *acetabular* margin. This may *cause proliferation* of bone, blockage of motion, and pain. Ligaments are cut. *Dislocation is possible*
7. The patient lies on the sound side. The knee and thigh are flexed to a *right angle*. The thigh is *internally* rotated so that the *foot points* upward toward the *ceiling*. The prosthesis is inserted with the *posterior* aspect of the neck looking upward in the wound.	7a. The patient lies on the sound side. The knee and thigh are *partly flexed*. The thigh is *externally* rotated, and the *foot* lies on the *table*. The prosthesis is inserted with the *anterior* aspect of the neck looking upward in the wound.

distal insertion into the linea aspera is divided if more exposure is needed. The sciatic nerve lies directly under the skin incision. It is dissected free with the fingers, and the small branch to the short external rotators that contains a sensory nerve to the posterior hip capsule is cut. This may aid in relieving postoperative pain. Fatty tissue is removed from behind the hip and the short external rotators (the gemelli and obturator internus) are clearly visualized. The insertion of these is removed from the intertrochanteric ridge. The capsule is incised longitudinally along its posterior aspect from below upward to the acetabulum. The distal insertion of the capsule is reflected from its posterior attachment. Through this opening the femoral head can easily be dislocated by internally rotating the flexed thigh so that, with the knee flexed to ninety degrees, the foot points upward toward the ceiling. At times the insertion of the piriformis and a portion of the quadratus femoris insertion have to be removed. The head is pried out with a skid or removed with a screw to prevent breakage of the femoral shaft. Good femoral heads are preserved in the bone bank for grafting in other cases. In fresh femoral neck fractures the head is usually removed with two screws. The ligamentum teres is carefully removed from the joint. The neck is sawn across at the proper angle and a rectangular slot is made with a special hollow chisel. This slot is to receive the stem of the prosthesis. It is deepened with a special rasp until fitting is perfect. The slot is cut obliquely across the femoral neck so that the fin on the outer side of the inserted prosthesis points toward the posterior part of the greater trochanter. This preserves the normal anteversion of the femoral neck. The normal alignment of the femur is preserved and the patient is able to walk with the foot pointing directly forward. The prosthesis may be used in either right or left hip. Measurements are made on roentgenograms prior to surgery. The head and acetabulum are measured with calipers at the time of surgery and a trial fitting of the prosthetic head is always made in the acetabulum. The fitting should be perfect, to distribute the stress properly and to avoid degenerative changes and pain. Cancellous bone removed from the femoral neck is placed in the stem fenestrations, and the prosthesis is inserted in the shaft. Care is taken that a tight fit is obtained

and the head is then driven in place. With proper measurements correct leg length is preserved in fresh fracture cases. In old cases with shortening due to absorption of the head and neck the capsule may be fibrosed and contractured. In such cases fitting a prosthesis high on the neck to regain leg length may stretch the capsule and cause pain. The head should be reduced by direct pressure with the fingers and thumb Forced twisting of the shaft in attempting reduction of the prosthetic head is responsible for many cases of bone breakage. It is difficult to dislocate again a properly fitted head, once it has been reduced.

Usually there is very little bleeding from this operation The posterior circumflex artery along the intertrochanteric ridge is the only vessel of any size that may give trouble. Usually no ligatures are necessary The capsule falls together in place. A few sutures of catgut are placed in the deep fascia and the wound is closed loosely with a few interrupted deep sutures of silk. A pressure dressing is applied.

One legged spinal anesthesia is the method of choice The patient sits up in bed, moves about freely and has lunch after operation. He is usually out of bed and up on crutches in a few days. Within a week or ten days he may leave the hospital. He is cautioned to use crutches and only partial weight bearing for six months, or until x ray examination demonstrates adequate new bone formation. He comes in for examination and roentgenograms each two months for the first year and at intervals of six months to one year afterward. He is admonished to use a cane and be careful throughout the remainder of his life Excessive pressure on a hip prosthesis can cause pain, just as excessive pressure on a dental prosthesis can cause sore painful gums Too much pressure applied too long can cause absorption and a loosening of the prosthesis Either a loose fitting prosthesis or absorption about a prosthesis may cause pain This has been demonstrated beyond question. Pain has been relieved by restricting weight bearing and by tightening of the prosthesis It is better to "beat trouble to the draw" by fitting the prosthesis accurately It is better to stay out of trouble than it is to try to get out of trouble

RESULTS AND DISCUSSION OF COMPLICATIONS IN THE FRESH FRACTURE GROUP

A total of 271 self locking hip prosthesis operations have been performed on 211 patients in the past nine years. There have been ten cases calling for use of bilateral prostheses. There were 114 operations in private patients and 107 operations in patients at the State Hospital where the author is in charge of the orthopaedic service. Of the 114 operations in private cases, twenty-eight were for acute fractures of the femoral neck. All 107 cases at the State Hospital were acute fractures. The study of all the cases has been interesting and some results are surprisingly good (Tables 35 and 36) A statistical report of the follow-up on all cases two or more years after operation was made in 1957[4] The present study is concerned chiefly with the results of prosthesis as applied in acute fractures of the femoral neck. Since 1934 the author has treated most of his private acute fracture cases with Moore adjustable nails. Four parallel nails have been placed in the bone widely separated from each other When the fracture has been treated early when the reduction has been perfect, and when the nails have been properly placed, excellent results have been obtained. These results have been reported in several articles—the latest in 1953

At the State Hospital most of the patients were mentally unable to cooperate in the postoperative care of hip nailing operations. Long-continued bed treatment with attendant care was necessary This was expensive and required additional personnel. Use of the prosthesis was begun in 1950. The results were so striking that the prosthesis gradually re

Table 35 Clinical Results in Twenty-Eight Acute Fractures (Private Patients No Complications)

Excellent	12
Good	9
Fair	2
Poor	0
No follow-up	5

Table 36 Results in 107 South Carolina State Hospital Patients With Fracture of the Femoral Neck

Operative deaths		2
Surgical shock	1	
Pneumonia one week after surgery	1	
Died later (senile changes cardiovascular disease)		23
Walking no complaint		38
Walking with complaint of pain		12
Using wheel chair		2
Dismissed from hospital in good mental and physical condition		30

placed hip nailing without its being realized. Now the prosthesis is considered by all members of the medical and nursing staff as the method of choice in all acute fracture cases. The medical nursing and attendant staff all agree that the results with prostheses are far superior to those of hip nailing procedures. Practically all intertrochanteric fractures are treated by fixation with a Moore blade plate. The prosthesis patients are not restrained and are allowed to be up and about as they please.

The twenty-eight private acute fracture patients, for whom the utmost protective care has been used have been studied in contrast to the 107 State Hospital cases in which there was no control. It must be remembered that in the State Hospital cases the patients are usually malnourished and in poor physical as well as poor mental health. Their vitality is low and their resistance to infection is low in comparison.

Among the total 135 patients with acute fractures there were two operative deaths and four major and five minor complications that will be listed. All of these complications occurred in the State Hospital group of 107 patients. There were no deaths and no complications in the twenty-eight private patients.

In the State Hospital group the two deaths from surgery were as follows one patient died of surgical shock and the other died of pneumonia one week after surgery

Complications in
State Hospital Patients

Major Complications

1 J C. Severe infection. It is interesting that in this case the floor of the acetabulum completely melted away within a few months, with central protrusion of the prosthesis. The patient died five months after surgery from sepsis.

2. H. T H Moderate infection. Patient died four months after surgery Infection and poor physical condition.

3 J J Old osteomyelitis of femur with recurrent infection. In this case roentgenograms of the hip fracture did not include the middle third of the femur While driving in the prosthesis, peculiar hardness was encountered. Subsequent x ray examination revealed an old fracture of the middle third of the shaft which had been plated. There was obvious infection and the prosthesis was therefore removed. The patient is doing well three years after surgery

4 M G Dislocation of prosthesis. This probably occurred during a epileptic seizure The patient died of cardiovascular complications three months after surgery

Minor Complications

1 C. C. Moderate bone proliferation about prosthesis. Patient walks with limp has no complaint

2. J C. Mild bony proliferation about the femoral neck Femoral shaft is osteoporotic The patient limps but is catatonic and makes no effort to walk is satisfied.

3 N L. This patient had a low neck fracture Roentgenograms three and one-half years after surgery show some settling of prosthesis in shaft with slight motion. There is a slight limp but no complaint.

4 L. P Slight bony proliferation about neck. Patient does not walk much and has no pain. In old age he makes very little effort to walk.

5 C. N Patient in old age does not walk, makes no effort, and offers no complaint. Roentgenograms look perfect.

It must be remembered in considering the State Hospital group not only that these were patients elderly feeble and in poor physical condition but also that many of their operations were performed by junior associates and the resident staff in training After a critical study of the twenty-eight private cases with no complications and the 107 State Hospital cases with comparatively few complications, the results are considered so satisfactory that it seems possible that the prosthesis may prove to be the method of choice in all acute neck fractures. We have subconsciously come to prefer the prosthesis for all acute fractures in patients over the approximate age of 60 years. Certainly the indications seem clear in all elderly patients with high, vertical, subcapital Pauwels type 3 fractures.

With experience and the results that have been obtained so far the concept concerning indications for prostheses has gradually changed, the inclination being more and more in favor of the prosthesis.

COMPLICATIONS IN ALL GROUPS (221 OPERATIONS)

An attempt will be made to discuss in general the total series of 221 operations. Any surgery of this magnitude is bound to carry with it a calculated risk of morbidity and mortality Especially is this true when a large number of elderly enfeebled, mentally and physically ill patients are included.

Cardiac arrest, shock, embolus, hematoma formation, infection phlebitis, etc. are common complications of all major surgical procedures Complications of this operation frequently described are operative mortality shock, infection, dislocation, fracture of the femoral shaft, breakage wearing away or irritation of the prosthesis, protrusion of the prosthesis from the side of the shaft loosening settling and "toggle" of the prosthesis, postoperative new bone formation and calcification about the prosthesis, stiffness of the hip sciatic nerve palsy fatigue breakage of the prosthesis, pain and limp.

Operative Mortality In the 221 operations there were three deaths as a direct result of surgery one from cardiac arrest, one from surgical shock, and one as a result of pneumonia one week after operation.

Shock. Most patients have no appreciative surgical shock. No preoperative opiates are given. The usual medication is 1½ grains of Seconal the night before and the morning of operation. A light breakfast is allowed. A low one legged spinal anesthetic is used. The operation is usually completed in one-half hour to forty-five minutes. Blood is usually administered. The patient is prepared psychologically and is usually told, "The operation will be a real pleasure." All the above factors are considered important in bringing the patient through the operation successfully with no apparent shock. They usually go to the recovery room and have lunch on schedule

Infection. If infection follows operative repair of a fractured hip, it may be either major or minor

Major There were three severe operative wound infections—all in the group of 107 State Hospital patients. One of these infections was relighting of an old osteomyelitis that followed plating of a fracture of the mid third of the femur This area was not included in the film made of the femoral neck fracture. That patient should not have been operated on. The prosthesis was removed and he is doing well 3½ years later The other two patients had severe infections and died within a few months. In one of these patients the prosthetic head protruded into the acetabulum. This substantiates the contention I have always maintained that deepening of the acetabulum or protrusio-acetabuli in prosthesis operations is due to a low-grade infection.

A fourth infection that occurred in the total 221 operations was relighting of an old osteomyelitic hip infection. A prosthesis was used in this case in an attempt to improve motion. It was understood that the infection might recur The infection did recur two years after surgery The prosthesis was removed. It should never have been inserted.

Minor There were four superficial wound infections that gave no especial trouble

Complications Rare or Not Encountered in This Series. A number of frequently reported complications have not proved to be problems in our series.

1 *Phlebitis and hematoma formation.* These have not occurred to any appreciable extent.

2 Dislocation or subluxation of the prosthesis. This has not occurred in a single uncomplicated case but has occurred in one case where infection was present and in another patient during an epileptic seizure. When the head is fitted accurately in the acetabulum redislocation is most difficult even under anesthesia

3 *Fracture of the femoral shaft. There has been* no case of bone breakage while inserting the prosthesis. The stem is fitted accurately in the shaft with the rasp or special chisel. Care is taken to prevent excessive hammering when the prosthesis is driven in place. The head is reduced by direct pressure with the hands. This eliminates torsion stress on the femoral shaft.

4 Breakage of the prosthesis. There have been no broken prostheses. We think the size and shape of the prosthesis distributes the stress. Vitallium metal is strong and apparently it is able to carry the stress load. I know of no Moore Vitallium prosthesis that has broken.

5 Wearing away or irritation of the prosthesis. This has not occurred in a single instance. Acrylic, nylon, or plastic heads will wear away and may cause severe irritation. It has even been suggested as a cause of malignancy Stainless steel has greater tension strength than Vitallium but the shape of the Moore prosthesis is such that there is very little springlike action. Stainless steel is not standardized and the quality may vary with the different manufacturers. Heat and machining may alter its properties considerably Abrasives and buffing or polishing compounds used in the polishing process may be ground into the surface. This may cause oxidation and corrosion when buried in the body tissues. Titanium is being recommended by some for prosthesis. In its pure state titanium is essentially inert but the composition of the commercial product may vary with various manufacturers. The principal claim of titanium is its comparative light weight. An ounce or even a pound's difference in weight at the hip makes no difference as it is at the center of the arc of motion and not at the periphery If the weight were being placed at the foot as at the end of a pendulum it could make considerable difference

Vitallium appliances are manufactured with exacting care and precision. Each one is x rayed and carefully tested for flaws. Composition of the metal is standardized. It has been proved to be inert and nonelectrolytic in the tissues. In 22 years of use over 7,000,000 Vitallium appliances have been surgically implanted and there has never been one authenticated case of corrosion reported. Vitallium is a cast metal and thus lends itself more easily to the

manufacture of the Moore prosthesis than does stainless steel which requires the process of machining. Vitallium is the author's material of choice and theoretically it may last indefinitely and give satisfactory service throughout a patient's expected life span.

6. Protrusion of the stem of the prosthesis from the side of the femoral shaft. This incident has been reported a number of times by others but it has not occurred once in my experience.

7. Loosening, settling and "toggle" of the prosthesis. In one instance I used a prosthesis, the stem of which had been cut off about 2 inches. That prosthesis became loose with weight bearing. There was a "toggle" and the patient could feel and hear the prosthesis click. Tightening occurred and pain was relieved by restricted weight bearing. This case demonstrated that the stem must be sufficiently long. We are careful not to ream out or remove too much bone from the femoral neck. The slot in the neck is made carefully. It is enlarged with the rasp until it is just barely large enough to receive the prosthesis stem. By fitting and seating the prosthesis carefully and by restricting weight bearing after operation, loosening and settling and "toggle" have been limited to very few instances.

8. Postoperative new bone formation and ossification about the prosthesis. This has been observed in a considerable number of cases. We believe that this is being limited by careful handling of the tissues, removing all turned back periosteum, loose bony tissue, etc.

9. Stiffness of the hip. This has been observed in only two or three instances where the prosthesis was fitted tightly. We feel that we eliminate stiffness by precision and using no postoperative support. The patient moves freely after surgery, is soon up and about, and usually has full, normal motion of the hip.

10. Sciatic nerve palsy. This has not been seen, either partial or complete, in any of the cases. Injury to the nerve is avoided by its deliberate exposure and retraction as it lies in the floor of the wound. The small branch containing sensory fibers from the hip capsule is resected to help relieve pain.

11. Fatigue breakage of the prosthesis. This has not occurred in any of the 221 cases. I have never seen or heard of a broken Moore Vitallium prosthesis.

12. Pain and limp. Excessive weight bearing and a loose prosthesis causes pain. Our patients are cautioned concerning this. They are told to take it easy and use a cane all their lives. Most patients are very comfortable. Of course low-grade infection will cause pain. In one case I could not explain pain that the patient complained of. Months went by; she still complained. I even reoperated and redislocated the hip, looking for the cause of her pain, and none could be found. The patient was a spry, delightful little old lady, 70 years of age and weighing about ninety pounds. She was allergic to many things and to most foods. She drank cocktails and ate only sparingly of tidbits. She was very active, attractive and charming, but she used crutches and complained bitterly of pain. Finally, two or more years after surgery a little absorption was seen about the prosthesis. I think her catabolism was simply a little more than her anabolism. With improvement of her general health and habits her pain improved.

A considerable number of the total 221 patients walked with some limp. The limp usually occurred in those patients who had advanced pathology in the hip that had been present a long period of time. Many of these patients had irremediable shortening. Relief of pain was the principal objective in using the prosthesis. Most of the acute fracture cases had little to no limp. Some of the patients say they can scarcely "tell one hip from the other." Some State Hospital patients limp from force of habit or from indifference. No important muscles or supporting tissues are divided in the typical operation as described. The patients resume their activities early and theoretically there should be no limp in the uncomplicated hip problem.

INDICATIONS FOR PROSTHESIS IN ACUTE FRACTURES

The immediate use of a self locking hip prosthesis is considered indicated in acute femoral neck fractures in the following conditions:

1. High subcapital vertical Pauwels type 3 fracture in the aged. The prosthesis in these cases may be used with justification at age 50 or lower—possibly at any age.

2. Patients with Parkinson's disease, partial paralysis, or other conditions where crutch walking or protected weight bearing is difficult.

3. Wheel chair or bedridden patients—especially those in terminal illnesses who get out of bed, stand on their feet, and take a few steps. A prosthesis can make these patients comfortable and lessen the need for nursing and hospital care.

4. Patients with metastatic malignancy. The life span cannot be estimated in many of these cases.

The patient can be made comfortable and may live a long time.

5 Patients with aseptic necrosis of the head following radium therapy These conditions not infrequently follow radiation therapy for cancer of the cervix. Copeland has shown that death of bone extends well down into the base of the femoral neck. Fractures of the neck cannot heal with nailing A prosthesis is clearly indicated.

6. Patients taking shock therapy Hip nailing of fractures in these patients may delay treatment by months. A prosthesis is indicated.

7 Rheumatoid arthritis with multiple joint involvement. Nailing fractures in these cases increases the period of inactivity and may increase joint stiffness and pain. A prosthesis allows early resumption of activity and may improve joint motion and decrease pain.

8. Fracture of the avascular necrotic head in young people. This is usually the result of "caisson disease or of traumatic dislocation of the hip. The choice of treatment must either be hip fusion or a hip prosthesis. A prosthesis is recommended with fusion later by an intramedullary rod through the posterior part of the pelvis and down into the femur if ever the prosthesis breaks down and fusion is necessary

9 Fractures of the avascular necrotic or "cystic degenerated" femoral head in older patients. This condition comes on with the repeated trauma of weight bearing or perhaps with a fall. The head is crushed, flattened misshaped and roughened. Sequestrations take place and pain may be severe. A prosthesis should be used early as ultimately there may be similar degenerative changes in the acetabulum with a "wandering socket" and a shallow decompensating acetabulum to receive the prosthesis when finally it is applied. Early operation is indicated in these cases.

10 Traumatic dislocation of the hip with fracture of the femoral head When a considerable portion of the head has been broken off the likelihood is that avascular necrosis with crushing of the head and disabling pain will develop The immediate use of a prosthesis is indicated

11 Fresh fractures of the femoral neck in mental patients and possibly others The indication is clear that a prosthesis is the treatment of choice in mental patients or patients unable to cooperate in their aftercare The average run of other patients with femoral neck fractures may have better results with well-performed prosthesis operations than with the average nailing operation. Impacted cervical fractures should be nailed. Low horizontal fractures of the neck in young patients should be nailed. If the surgeon has confidence that with a nailing operation he can bring about complete healing of a neck fracture, with minimal to no absorption of the neck and minimal to no necrosis of the head, then that fracture should be nailed. A perfectly healed fracture is unquestionably better than any prosthesis. The question is "how many perfect healings of fractures can be expected?" The final results depend on the wisdom of the surgeon in his selection of cases, his mechanical and technical skill in the execution of the operation, and his judgment in planning and supervising the aftertreatment until the end result is obtained. There is no doubt that in skillful hands, most fractures of the femoral neck in cooperative patients can be made to heal satisfactorily Time alone will tell what method is best suited for the average acute femoral neck fracture in average hands.

SUMMARY AND CONCLUSIONS

1 A history of the development of the Moore self-locking Vitallium hip prosthesis is outlined.

2. The results of 135 operations for fresh fractures are reported.

3. Results of operation in the fracture cases are pleasing and in most cases are superior to the other methods.

4 The indications for operation have been outlined. Mental illness in patients with acute femoral neck fractures is one of the indications.

5 Complications have been outlined and discussed.

6. The "southern exposure" approach to the hip has been described. It greatly facilitates the ease of operation and reduces the time easily to thirty to forty five minutes in the average case In one fresh fracture an attempt was made to set a speed record and the operation was completed in thirteen minutes

7 The importance of care and discretion in the selection of cases has been emphasized. The operation should be planned deliberately executed with precision, and followed with proper aftercare if good results are to be expected.

8 Results continue to be encouraging Possibly there is justification for some enthusiasm but unqualified enthusiasm should be withheld for many more years until a final evaluation of the benefits and the hazards of this method can be determined

For their invaluable aid I wish to express my gratitude to Dr Emmett Lunceford, Dr V L Kruger Mrs. Merle Esdreck, Mr J Maxwell Chappell, Mr C. L. Wise and Miss Myrtl Glasscock.

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SUMMARY

The purpose of this course has been eloquently fulfilled in that it has brought to you a nationwide cross section of the clinical experience from a group of representative orthopaedic surgeons who use prostheses in the treatment of fresh femoral neck fractures. There are those of the panel who do not favor the method, as well as those who have presented their particular type of prosthesis and technique. Still others have indicated flexible convictions with regard to type and procedure. The fact is that there are still many types of prosthesis from which to select and different ideas and opinions about the technique of the operation, which is evidence that the ideal prosthesis and procedure are still in an evolutionary state. Further, the fact that discussion concerning the materials used in the fabrication of prostheses has been brought up from the floor shows that the last word has not yet been said in regard to what metal or alloy is best. All this is indeed a gratifying sign of progress, and as long as research, biophysicists, metallurgists, and orthopaedic surgeons are not completely satisfied with designs and materials used, you can rest assured that improvements will continue.

From the literature and surveys we cannot determine what percentage of fresh femoral neck fractures are treated by prostheses. We know, however, that it must be a rather significant number. From the experience of the panelists and the surveys we can discern that this treatment should be reserved for patients of 60 years, 70 years, or older.

1. It appears that the mortality rate incurred in the use of a prosthesis for such fractures of the femoral neck is no greater than that with reduction and internal fixation. This is particularly true when the technique is carried out intelligently on a patient who is a well-evaluated risk, with an atraumatic approach and the best type and size of prosthesis, seated properly by a surgeon who has the know-how.

2. Earlier ambulation is possible by this method. Some patients can be gotten out of bed and on crutches even the day following surgery. Others can be encouraged to activity as they feel physically able. Caution must be exerted in most instances to prevent damage by too-early full weight bearing and activity.

3. Most of the panelists observe that the patients have a shorter hospital stay because of their early ambulation and well being.

4. There seem to be fewer late complications from this method, such as nonunion and aseptic necrosis, which are eliminated. Further, seldom is there extension of the osteoarthritic changes in the acetabular margin. However, resorption may occasionally occur in the presence of malignancy, osteoporosis, or other bone pathology.

5. A few patients have pain in the hip after convalescence. Pain has not been accounted for.

6. All the factors lend finality to this procedure, which gives emotional and economic assurance and satisfaction to the patient and to his postoperative well-being.

There are still many questions unanswered by the panelists that deserve thoughtful consideration and it is unfortunate that time does not permit formal consideration of such things as narrowing of the joint space after operation, absorption of the acetabulum and resorption of the bone in the shaft causing settling of the stem change of position, wobble and instability. Little has been said about the cause of pain when it does exist. True some of these subjects have been touched upon by some of the panelists but only in a superficial manner. Research and study are needed to answer these and many other questions that will be raised during the question period.

There are few reports in the literature which deal with a large series of patients treated by this method, and you have observed that the panelists all have assumed a very conservative approach toward this method. I personally have been very much interested in the personal communications of two mid west-southern groups. I refer to Dr Wm J Stewart and Dr Glenn L. McElroy of Columbia, Missouri and Dr P L. Day and Dr J J Hinchey of San Antonio, Texas.

In the summer of 1958 Dr Stewart wrote me that since 1952 he has placed more than 300 hip prostheses in patients having fresh fractures of the femoral neck, and Dr Hinchey wrote that they have placed prostheses in an equal number of such fractures of the femoral neck. Both these groups have made several important observations. First they use this method routinely for all fresh fractures in patients over 60 years of age. Some have been over 100 years of age. Further they call attention to the facts that (1) the surgeon should always have plenty of different types and sizes of prostheses available to meet the particular needs of the fracture (2) the earlier operation can be performed after the patient becomes a surgical risk the better are its chances of success (3) this enables them to establish early a better walking pattern and (4) there is no established pain reflex and less muscle atrophy.

These two groups feel that they have achieved uniformly satisfactory results with this treatment.

I wish it were possible for us to have a very careful analytical study of these results and similar studies made of other large series throughout the country. The only way the results can be judged appropriately might be through establishment of a standard method of appraisal—or perhaps more than one type of appraisal, for different schools of thought. For instance today we heard the opinion expressed that this operation should not be performed for a patient who would not be able to walk. In contrast, there were those on the panel who felt that there was a place for prosthesis usage in a certain group of patients who would never be able to walk even with crutches.

The topic of medicolegal implications of the use of prostheses is something that deserves consideration, since at the present time work is being done to establish a beachhead for the introduction of a number of suits relative to complications following the use of prostheses. I am indebted to Dr Charles J Frankel of Charlottesville Virginia for the information in hand.

It is evident that it is the surgeon's responsibility to thoroughly acquaint the patient, in the presence of witnesses and before operation with all the possible difficulties that may arise in the use of prostheses. Such information should be placed in the case record, where it can be shown that the patient was given the information. A release from the patient is of no use since no law will recognize such a release as relieving the physician of his responsibilities so far as negligence is concerned.

Dr Frankel also points out that "the law warranty is being utilized against the prostheses as well as the *Pure Food and Drug Act*. The latter may be used wherein the metal objects are sometimes mislabeled as to size and content."

I am sure that much more will come out on these legal aspects as use of the prosthesis is popularized and we, as surgeons, should keep abreast of the legal aspects of this problem.

We the panel, appreciate your maintained interest throughout this rather long session and hope that our contributions have proved stimulating and helpful.

INDEX

A

Abdominal fascial transplants in treatment of scoliosis, 197
and sacrospinalis muscles in paralytic scoliosis, role of 196
Abscess development in osteomyelitis, 234
Achilles tendon, taping, 27
Acquired disorders causing inequality in leg length, 220
Acromioclavicular joint, taping 25
Action potentials, recording equipment for 248-249
of vastus lateralis on knee extension, 257
Adduction deformity of fore part of foot, anterior capsulotomies for 101 110, 111 113
of heel in clubfoot, medial capsulotomies for 110 114-116
Adductor muscles, action of, in locomotion, 253 255
taping, 7
Adults, operative treatment of fractures of elbow in, 265-276
Afflictions of menisci of knee 156-157
Age of patient, relation to prosthetic replacement in hip fractures, 294
Aluminum filter for bone density measurement, 285
Ambulation, early in patients with femoral head prostheses, 322
postoperative weight bearing, by means of prosthetic replacement, 294
Analysis of curves of spine 184 196
of forces in correction of scoliosis, 208-210

Anatomical considerations, acute hematogenous osteomyelitis, 232
Anatomy comparative of menisci of knee 153-156
of hand, 53-69
functional, 80
structural, 80-82
of thumb 80-82
Anesthesia in treatment of Dupuytren's contracture, 78
Ankle fractures, 37-42
injuries, analysis of, 41
examination of 35
internal rotation-adduction, 42
mechanisms, 37
in sports, 35-44
treatment, 37 39
muscle rehabilitation, 48
sprain, effect of compression on, 43
grades of 40
treatment, 39
taping 26
wraps, 35 36
Anterior capsulotomies for correction of fore part of foot in clubfoot and metatarsus varus, 101 110 111 113
Antibiotic therapy of acute hematogenous osteomyelitis, 236-238 239
of osteomyelitic lesions, results of 237 238
during saucerization and primary closure 243-245
timing and intensity of dosage, 237
Antibiotics broad-spectrum, in staphylococcal infections, 237
combination of in treatment of osteomyelitic lesions, 237
for low-grade hip infections following surgery 308

Antibiotics—Cont d
new in treatment of osteomyelitic lesions, 237
Arachnodactyly scoliosis with, 207 208
Arch, longitudinal, taping 26
Arm, muscle rehabilitation, 47
Arthritis, acute osteomyelitis differentiated from, 235
cervical, in football players, 20
chronic, of spine, 176
in knee joint, 164 166
Arthrodesis, triple in correction of valgus deformities, 132 134 136, 137
Articular cartilage degenerative lesions of, 166
Aseptic necrosis of femoral head following radium therapy prosthesis for patients with, 320
Asymmetry and growth adaptivity of man, 19
Athletes, body types, 18 19
injuries to closing comments, 49
opening remarks, 13
orthopaedist role in prevention, 14 15
prevention of 17 28
physical examination important, 18
protective equipment for 21
rehabilitation, 45-48
return to activity 48
taping of 21 25-27
training and conditioning of 20
weight-training routine 22 25
Athletics, ankle injuries in, 35-44
appeal to masses, 13
benefits of 14
importance to individual 14
knee injuries in, 29-34
physicians' interest in, 13
prevention of injuries in, 17-28
scholarships, 14

Atrophies of central origin differentiated from myopathies by electromyography .56-257
A ascular necrotic femoral head fractures, prosthesis for 320
Axis, mechanical, of low extremity study of 253 54
of subtalar joint, electromyography in study of .51 252 253

B

Back pain, low of discogenic origin, surgery for 178-179
industrial 175-182
intractable special management, 180
relief of after removal of protruded intervertebral disc with and without fusion. 215 216
routine management, 180
remedial exercises, 46-47
Backache postural, 173
relief of after removal of protruded intervertebral disc with and without fusion, 215 216
Bacteria, invasiveness and toxigenicity of 234
spreading factor 234
Bacteriological considerations in acute hematogenous osteomyelitis, 234
Bayley stature graphs, 22?
Blood stream nfections, 236
supply of long bone 233
of palm of hand. 57
Body alignment importance sports 18
compensation of 184
Bone age hand plates for 228
n prediction of growth of extremities ?23
density measurement, 286
aluminum filter for 285
grafts a tarsal sinus, insertion of 130
injuries bout knee 3. 34
long natomy 33
blood supply 233
Brachial rtery injury with elbow fracture 275
Broad-spectrum ntibiotics i therapy of osteomyelitic nfections, 237 239
Brockman operation on heel in clubfoot, 110
B nnell transplantation in repair of lawed fingers 85
of thumb lawhand 85

C

Cal neovalgus, ongenital onvex pes algus differentiated from, 117
Calf taping 7
Capitellum fractures, ?71
Capsulotomies, anterior for correction of fore part of foot in clubfoot nd metatarsus varus, 101 110 111 113
medial, for correction of heel in clubfoot, 110 114 116
release operation for clubfoot, 99
Carcinoma, pathological fracture due to 293
Cartilage, articular degenerati e lesions of, 166
Cerebral palsy algus deformities caused by subtalar fusion in, 145
"Charley horse treatment of, 46
Chemical therapy of osteomyelitic infections 236
Child's expected extremity growth, methods of calculating, 221 230
Chimpanzee and man, comparison of growth of 219
Chondromalacia of patella and femur 166-169
Chroni osteomyelitis, 241 245
Circulatory considerations acute hematogenous osteomyelitis, 233
Clawed fingers, new method of repair 88
surgical repair of, 85-88
Clawhand, cause of deformity in, 79
surgical repair 82-88
Clubfoot, congenital, and metatarsus varus urgical release of fibrous tissue structures resisting correction of 100-116
exercises, 95
medial capsulotomies for correction of heel in, 110 114-116
nd metatarsus varus anterior capsulotomies for 101 110 111 113
release operation, 93-99
splints, 94 95
treatment, 93-99
types 94
Coaxial electrode 247 248
Colla of prosthesis for hip fract res. 303 304 305
Comminuted fracture of femoral head and neck, 292
of head of radius, 266, 267
Comparative anatomy of menisci of knee 133-136
Compartments of wrist, 54-55
Compensation of body 184
Complications of femoral neck fractures with prosthetic replacements, 296
not encountered i self-locking hip prosthesis operations, 318-319
of self-locking hip prosthesis operations, 317 318
Complications—Cont d
of treatment of hip fractu prostheses, ?81 2 286 289-291
Compression for ankle sprai of 43
fracture of radius, 266
Condyle of femu medi chondritis disse 164-165
Congenital clubfoot and m varus, surgical r fibrous tissue s resisting correct 100-116
treatment, 93-99
convex pes valgus, diagno 120
treatment, 121 126
subtalar fusion 1
disorders causing inequalit length, 220
scoliosis, 203-205
Contractures as cause of ine in leg length, 2?0
Dupuytren s, 70-78
Contraindications for use of es in hip fractu
Convex pes valgus, congenita nosis, 117 120
subtalar fusion in tr of, 139 145
treatment, 121 126
Coronoid process, fracture 270
Cortex, motor electromyogr study of 251
Creases of hand 55
Cripple, low back, industria nosis, treatment, habilitation of 17
Curves of spine nalysis of diagram of locations of
Cystic degeneration of menisc

D

Dead heads from overradiati dication for use oral head prosth hip fractures, 300
Decompression, early i oste tis, 238, 239
Decubiti, postoperativ comp of insertion of head prosthesis 2
Deformities produced by locali length of curves in 196
n clawhand, cause of ?9
Denis Browne splint for lubf
Density bone measurement o 286
Derangements, internal, of kne 169
Developmental disorders causi equality i leg lengt
Diagnosis, electromyography i treatment, and rehabilitati industrial low back ple 175-182

Digby s growth percentages for whole lower extremity 221
Digital nerves to fingers, 60
Digits, extensor hood of 66-68
Dihydrostreptomycin treatment of acute hematogenous osteomyelitis, 237
Disability permanent, evaluation of 181
Discectomy for low back pain, 178
Discogenic low back pain, surgery for 178-179
Discoid menisci, removal of 156
Discs, intervertebral herniated, electromyography in diagnosis of 231
lumbar protruded, end results of removal of, with and without fusion, 213-216
syndromes, 177 178
Dislocation of elbow 273-275
of femoral head complicating fracture of femoral neck, 292
of hip, traumatic with fracture of femoral head, prosthesis for 320
of prosthesis following operation on hip fractures, 282 84-286 289
Disorders causing inequality in leg length, 220
Distraction, forces of in correction of scoliosis, 209
plaster jacket for scoliosis, 210
Dorsiflexion in presence of tibialis anticus paralysis, 254
Dorsum of wrist nd hand, anatomy 54 55
Dual electrodes, 247 248
Dupuytren contracture 70-78
anesthesia in treatment, 78
etiology 70
grades of 74
nodules, 71 74
nonsurgical treatment, 75
pathogenesis, 70-74
surgical therapy 75-78

E

Effusion traumatic in knee injury 29
Eicher prosthesis for hip fractures, 301 303 304
Elbow dislocations of 273-275
fracture-dislocation of, 274
fractures in adults operative treatment, 265-276
complications, 275
restricted motion following 275
joint, open fractures, 273
T-fractures into, 272
muscle rehabilitation 47
taping 26
Elderly patient, femoral head replacement in 298 299
Electrodes, types of, 247 248
Electromyogram, electrophysiological basis of 246
Electromyograph c records, typical, 49
Electromyography 216-261
applications in orthopaedic surgery 250-261
in detecting level of spinal cord lesions, 251
in diagnosis of poliomyelitis, 250
in differentiation of myopathies and atrophies of central origin, 256-257
in study of extraocular muscles, 255
of innervation and denervation of muscle 256
of locomotion, 251 261
of normal muscle function, 257
of phasic activity of quadriceps, 259 260
of subtalar joint axis, 251 252 253
Electrophysiological basis of electromyogram, 246
Embryology of menisci of knee 153 154
Epicondyles, lateral and medial, of humerus, fractures of, 271
Epiphyseal arrest, growth prediction by 223 225 226
disc growth percentages in poliomyelitis 229
fractures, femoral and tibial, 32 33
Epiphysis, anatomy 232
osteomyelitic lesion in 233
percentage of growth t, measurement of 223 225
Equinovalgus in spastic hemiplegia 146
Equinus deformities correction of, 131
Equipment, athletic protective 21
Examination, physical, before participation in sports 18
and treatment of minor ankle injury 39
Exercises, actv in rehabilitation of athletes 45
for clubfoot, 95
muscle three-cycle count, 46
remedial, for back, 46-47
after removal of menisci, 163 164
in treatment of scoliosis, 195
Extensor ommon, relation to subtalar axis, 252
transfer into dorsum of foot, subtalar axis in, 253
hood of digits, 66-68
tendon transplant, Fowler s in repai of clawed fingers 85 86 87
Extra rticular fractures about knee 3
fusion of subtalar joi t for algus deformities 132
Extraocula muscles, electromyography in study of 255
Extremities, lower action of muscles of 253 255
Extremities, lower—Cont d
expected growth increments of methods of calculating 221 230
growth of pr ferred methods for prediction of 228
mechanical axes of 253 254
shortening after poliomyelitis relation to muscle power 226
unequal, surgical care of 219-230

F

Fascial transplants abdominal in treatment of scoliosis 197
Fasciatome 76
Fasciculation definition, 247
Fasciotomy subcutaneous, in Dupuytren contracture 75-78
Feet (*se also* Foot)
congenital deformities clubfoot treatment, 93-99
Femoral head prosthesis, indications for 292 294
Moore s, 309
postoperative management of patient with 294
replacement with, 292
survey 80
size of 306-307
surgical technique of insertion, 295
versus internal fixation of hip 299-300
ne k fractures, acut indications for self-locking hip prosthesis in, 319-320
compl cations after primary prosthetic repla ement, 284-286
fresh, Moore self-locking Vitallium prosthesis in, 309-320
prostheses for summary of discussion, 322 323
historical background of treatment, 278-279
indications for prosthesis in, 288
in mental patients, prosthesis for 320
preoperative d postoperative management, 294
primary prosthetic replacement in, 283-286
with prosthetic replacements, complications of treatment, 296
results of self-locking hip prosthesis operations in, 316
of treatment by prosthetic replacement, 297
statistical review of use of prosthesis in, 280-282
symposium on treatment of 278-323
treatment with prostheses, 292 298

Femur medial condyle of osteochondritis dissecans of 164-165
patella and, chondromalacia of 166-169
Fenestrations in stem of intramedullary hip prostheses, 306
Fibrillary potential as diagnostic sign, 247
Fibrous, periarticular after elbow injuries, 275
Fibrous tissue structures resisting correction of congenital clubfoot and metatarsus varus, surgical release of, 100-116
Fibula, adduction-external rotation fracture, 43
Fibular key to analysis of ankle injuries, 41
Filter aluminum, for bone density measurement, 285
Fingers, anatomy 80-82
clawed, surgical repair of, 85-88
extensor hood of, 66-68
and hand, taping 26
metacarpal and interphalangeal joints, 68
muscles, anatomy 82
rehabilitation, 47
nodules of Dupuytren's contracture, 72, 73
surface anatomy 53
tendons 60-62
Fixation, internal, of femoral neck fractures, historical background, 278
of hip, versus metal femoral head, 299-300
Flatfoot, congenital convex pes valgus differentiated from, 117
Flexibility of athlete examination of 19
Flexor tendons of fingers 62
Foot 91 150
fore part of, anterior capsulotomies for adduction deformity of 101 110 111 113
hind part of medial capsulotomies for deformity in clubfoot, 110 114-116
motions involved in running 17
muscles diagrams, 251 252 253
rehabilitation, 48
nodules of Dupuytren's contracture 4
operative technique of subtalar fusion 129 131
valgus deformities of subtalar fusion treatment, 127 150
Forces used in correcting scoliosis 193-194
Fowler extensor transplant in repair of clawed fingers, 85 86 87
tenodesis in repair of clawed fingers, 87

Fracture-dislocations of elbow 274
Fractures, 263-323
ankle, 137 142
avascular necrotic femoral head, prosthesis for 320
capitellum, 271
coronoid process, 267 270
elbow in adults, operative treatment, 265-276
complications, 275
open, 273
femoral neck (*see also* Femoral neck fractures)
fresh, Moore self-locking Vitallium prosthesis in, 309-320
treatment with prosthesis, symposium on, 278-323
primary prosthetic replacement in, 263-286
hip (*see also Femoral neck fractures*)
delay in treatment indication for prosthesis, 294
"falling apart" after reduction and nailing, prosthetic replacement, 294
fresh, choice of prosthesis, 301 307
indications for prosthesis, 299-300
treatment with prosthesis, 292 298
intracapsular fresh, use of prosthesis in, 287 291
poor reduction of indication for prosthesis, 293
humerus, 270-273
lateral and medial epicondyles, 271
knee 32 34
olecranon, 270
patella, osteochondral, 168, 169
Pauwel's type 3 prosthesis indicated for 294
radius head, 266-267
of spine, 174-176
differential diagnosis of 175
treatment, 175-176
T into elbow joint, 272
transcondylar 273
trochlea, 272
ulna, 268-270
Fresh fracture, definition, 292
femoral neck fractures, Moore self locking Vitallium prosthesis in, 309-320
treatment with prosthesis, symposium on, 278-323 (*see also* Femoral neck fractures)
hip fractures, choice of prosthesis, 301 307
indications for prosthesis, 299 300
intracapsular use of prosthesis in, 287 291
treatment with prosthesis, 292 298

Fulminating cases of acute hematogenous osteomyelitis, 233 239
Functional anatomy of hand, 80
Fusion areas in scoliosis, 190 192, 193
types of curves 194
of curves of spine errors in, 193
spinal, in correction of paralytic scoliosis, 198 200 201
end results of removal of protruded lumbar intervertebral discs with and without, 213-216
indications for with operation for removal of protruded intervertebral disc, 213-214
operation to relieve low back pain, 179
subtalar in treatment of valgus deformities of feet, 127 150

G

Gibson approach, insertion of femoral head prosthesis through, 295
posterolateral in hip fractures, low posterior approach compared with, 314-316
Gill and Abbott's method of growth prediction, 223
Goat and man, measuring percentages of growth in, 221
Goff's calculations of growth, 228, 229
Grafts, bone in tarsal sinus, insertion of 130
Grice procedure of stabilization of reduction of congenital convex pes valgus, 126
Growth adaptivity asymmetry and, of man, 219
of chimpanzee and man compared, 219
curves, Bayley's 222
increments of lower extremity expected, methods of calculating 221 230
inequalities in, conditions with, 220
prediction, Gill and Abbott's method, 223
of unequal extremities, measuring and predicting 219-230

H

Hamstrings, electromyographic study of, 254 260
taping 27
Hand, 53-90
anatomy 53-69
Dupuytren's contracture 70-78
functional anatomy 80
intrinsic muscles, 63-66
palm of anatomy 57-63
paralytic, surgery of 79-89
plates for measuring bone ages, 228
skin of 53

Hand—Cont d
structural anatomy 80-82
surface anatomy 53
taping, 26
tendons of 54-55
venous drainage 53
Hark operation for congenital convex pes algus, 142
Head of radius, fractures of 266-267
Healing of surgically treated osteomyelitic lesions, problems of 242-243
Hemarthrosis in knee injury 29
Hematogenous osteomyelitis acute 232 239
postacute 240-241
Hematoma in "Charley horse, 46
Hip, flexion contractures in athletes, causes of 19
fractures (*see also* Femoral neck fractures)
fresh, choice of prosthesis in, 301 307
indications for prosthesis 299-300
intracapsular use of prostheses in, 287 291
treated with prosthesis, 292 298
indications for prosthesis, 292 294
nailing of, arguments for and against, 299-300
primary prosthetic replacement in, 283- 86
treatment with prostheses, complications of 281 282, 284- 86
motions in ol ed in running 17
muscle rehabilitation, 47
pain after use of prosthesis, cause of 307 308
prosthesis in treatment of femoral neck fractures, historical background, 279
traumatic dislocation of with fracture of femoral head, 320
Historical background of treatment of fresh fractures of femoral neck, 278-279
Humerus, fractures of 270-273
Hydrocortisone in treatment of myositis ossificans, 275
Hyperemia, cause of complication in use of prosthesis in hip fracture, 291
Hypothenar eminence anatomy 82
muscles of hand, 65 66

I

Idiopathic scoliosis, 202, 203 204
Iliopsoas muscle electromyography in study of 254 256
Iliotibial band in causation of scoliosis, role of 197 201
Impairment, physical, medical rating of 181 182
Incision for a terior capsulotomy for adduction deformity of fore part of foot, 101 102
closure of release operation for clubfoot 99
for insertion of hip prostheses, choice of 307
low posterior in femoral neck fractures, 311 316
for operation on menisci of knee, 158-159
in release operation for clubfoot 96
skin, in tendon transfer in repair of clawhand, 83 84
Index finger extensor hood of, 67
tendon and nerve, 61
Industrial low back cripple diagnosis, treatment, and rehabilitation of 173-182
Inequalities in growth, conditions with, 220
Infants, acute hematogenous osteomyelitis in, therapy 239
Infection following self locking hip prosthesis operations, 318
operative after insertion of femoral head prosthesis, 296
Injuries, ankle 35-44
to athletes closing comments, 49
opening remarks 15
pre ention of 17 28
principles of treatment, 15 16
bone of knee 32-34
to elbow complications with, 275
knee 29-34
of menisci of knee 157 158
Ink writers for muscle studies 248
I ternal derangements of knee 161 169
fixation of femoral neck fractures, historical background, 278
of hip, ersus metal femoral head, 299-300
Interosseus muscles of hand, anatomy 64 81
Interphalangeal and metacarpal joints, anatomy 68
I terspace narrowed, as indication for fusion after operation for removal of protruded intervertebral disc 214
I ter rtebral disc syndromes, 177 178
disc lumbar protruded, end results of removal of with and without fusion, 213-216
Intra-articular fractures about knee, 32
Intracapsular fracture of hip, fresh, use of prosthesis in, 287 291
Intractable low back pain, special management, 180
Intramedullary prosthesis for *femoral* neck fractures, 280 284 285
for hip fractures, Moore's, 309
shape nd size, 302
I trinsic muscles of hand, 63-66
Invasiveness of bacteria, definition 234
Inversion of heel in clubfoot, medial capsulotomies for 110, 114 116
Involutional stage of nodule in Dupuytren s contracture, 71 74

J

Joint changes in Dupuytren s contracture 72 73 75
Judet method of treatment of femoral neck fractures, 279
prosthesis for hip fractures, 309

K

Kirschner wires in treatment of congenital convex pes valgus 126 142 145
Knee, 155-169
arthritis in, 164 166
extension, action potentials of vastus lateralis on, 257
fractures, 32 34
injuries, 29-34
in athletes, prevention of 28
bone 32 34
physical examination, 29
soft tissue, 29-32
internal derangements of 161 169
joint, dissection of 155
function of menisci, 155
incision and anatomy of lateral approach, 158
instability of 158
locking of, 161 166
loose bodies in, 165-166
menisci of comparative anatomy 155-156
cysts, 164
injuries and affections, 155-159
lesions, 161 164
surgical approaches, 158-159
tears, 162 163
muscle rehabilitation 47
taping, 27

L

"Last straw of stress, 174 176 177
Lateral forces in correction of scoliosis 208, 209
Leg length, Gill and Abbott s *method* of prediction, 223
inequalities in, causes, 220
motions involved in running, 17
Legal aspects of use of prostheses, 323
LeRoy Lowman operation, 73
Lesions of menisci, 161 164
osteomyelitic, development and extension of 234
manifestations of 235
pathogenesis of 233
saucerization and primary closure under antibiotic control, 243-245

Femur medial condyle of osteochondritis dissecans of 164-165
patella and, chondromalacia of 166-169
Fenestrations in stem of intramedullary hip prostheses, 306
Fibrillary potential as diagnostic sign, 247
Fibrosis, periarticular after elbow injuries, 275
Fibrous tissue structures resisting correction of congenital clubfoot and metatarsus varus, surgical release of, 100-116
Fibula, adduction-external rotation fracture 43
Fibular key to analysis of ankle injuries, 41
Filter aluminum, for bone density measurement, 285
Fingers, anatomy 80-82
clawed, surgical repair of, 85-88
extensor hood of 66-68
and hand, taping, 26
metacarpal and interphalangeal joints, 68
muscles, anatomy 82
rehabilitation, 47
nodules of Dupuytren's contracture 72, 73
surface anatomy 53
tendons, 60-62
Fixation, internal, of femoral neck fractures, historical background, 278
of hip, versus metal femoral head, 299-300
Flatfoot, congenital convex pes valgus differentiated from, 117
Flexibility of athlete, examination of 19
Flexor tendons of fingers 6*
Foot, 91 150
fore part of anterior capsulotomies for adduction deformity of 101 110, 111 113
hind part of medial capsulotomies for deformity in clubfoot 110 114-116
motions involved in running 17
muscles, diagrams, 251 252 253
rehabilitation, 48
nodules of Dupuytren contracture 74
operative technique of subtalar fusion, 129-131
valgus deformities of subtalar fusion in treatment, 127 150
Forces used in correcting scoliosis, 193-194
Fowler extensor transplant in repair of clawed fingers, 85 86, 87
tenodesis in repair of clawed fingers, 87
Fracture-dislocations of elbow 274
Fractures, 263-323
ankle, 137 14
avascular necrotic femoral head, prosthesis for 320
capitellum, 271
coronoid process 267 270
elbow in adults, operative treatment, 263-276
complications 275
open, 273
femoral neck (see also Femoral neck fractures)
fresh, Moore self-locking Vitallium prosthesis in, 309-320
treatment with prosthesis, symposium on, 278-323
primary prosthetic replacement in, 283-286
hip (see also Femoral neck fractures)
delay in treatment indication for prosthesis, 294
"falling apart" after reduction and nailing, prosthetic replacement, 294
fresh, choice of prosthesis, 301 307
indications for prosthesis, 299-300
treatment with prosthesis 292 298
intracapsular fresh use of prosthesis in, 287 291
poor reduction of, indication for prosthesis, 293
humerus, 270-273
lateral and medial epicondyles, 271
knee, 32 34
olecranon, 270
patella, osteochondral, 168 169
Pauwels' type 3 prosthesis indicated for 294
radius head 266-267
of spine, 174 176
differential diagnosis of, 175
treatment, 175-176
T into elbow joint 272
transcondylar 273
trochlea, 272
ulna, 268-270
Fresh fracture, definition, 292
femoral neck fractures, Moore self locking Vitallium prosthesis in, 309-320
treatment with prosthesis, symposium on, 278-323 (see also Femoral neck fractures)
hip fractures, choice of prosthesis, 301 307
indications for prosthesis, 299-300
intracapsular use of prosthesis in, 287 291
treatment with prosthesis, 292 298
Fulminating cases of acute hematogenous osteomyelitis, 235 239
Functional anatomy of hand, 80
Fusion areas in scoliosis, 190, 192, 193
types of curves, 191
of curves of spine errors in, 193
spinal, in correction of paralytic scoliosis, 198 200 201
end results of removal of protruded lumbar intervertebral discs with and without, 213-216
indications for with operation for removal of protruded intervertebral disc, 213-214
operation to relieve low back pain, 179
subtalar in treatment of valgus deformities of feet, 127 150

G

Gibson approach, insertion of femoral head prosthesis through, 293
posterolateral, in hip fractures low posterior approach compared with, 314-316
Gill and Abbott's method of growth prediction, 223
Goat and man, measuring percentages of growth in, 221
Goff's calculations of growth, 228 229
Grafts, bone, in tarsal sinus, insertion of 130
Grice procedure of stabilization of reduction of congenital convex pes valgus, 126
Growth adaptability asymmetry and, of man, 219
of chimpanzee and man compared, 219
curves, Bayley's, 222
increments of lower extremity expected, methods of calculating 221 230
inequalities in, conditions with, 220
prediction, Gill and Abbott's method, 223
of unequal extremities, measuring and predicting 219-230

H

Hamstrings, electromyographic study of 254 260
taping 27
Hand, 53-90
anatomy 53-69
Dupuytren contracture 70-78
functional anatomy 80
intrinsic muscles, 63-66
palm of anatomy 57-63
paralytic, surgery of, 79-89
plates for measuring bone ages, 228
skin of, 53

Hand—Cont d
  structural anatomy 80-82
  surface anatomy 53
  taping, 26
  tendons of 54 55
  venous drainage 53
Hark operation for congenital convex pes valgus, 142
Head of radius, fractures of 266-267
Healing of surgically treated osteomyelitic lesions, problems of 242 243
Hemarthrosis in knee injury 29
Hematogenous osteomyelitis, acute 232-239
  postacute 240-241
Hematoma in "Charley horse" 46
Hip, flexion contractures in athletes, causes of 19
  fractures (se also Femoral neck fractures)
    fresh, choice of prosthesis in, 301 307
      indications for prosthesis, 299-300
      intracapsular use of prosthesis in, 287 291
      treated with prosthesis, 29? 298
    indications for prosthesis, 292 294
    nailing of rguments for and against, 299-300
    primary prosthetic replacement in 283-286
    treatment with prostheses, complications of, 281 282, 84-286
  motions invol ed in running 17
  muscle rehabilitation, 47
  pain after use of prosthesis, cause of 307 308
  prosthesis in treatment of femoral neck fractures historical background, 279
  traumatic dislocation of with fracture of femoral head, 320
Historical background of treatment of fresh fractures of femoral neck, 278-279
Humerus, fractures of, 270-273
Hydrocortisone in treatment of myositis ossificans, 275
Hyperemia, cause of complication in use of prosthesis in hip fracture 291
Hypothenar eminence anatomy 82
  muscles of hand, 65 66

I

Idiopathic scoliosis, 202 203 204
Iliopsoas muscle, electromyography in study of, 254 256
Iliotibial band in causation of scoliosis, role of, 197 201
Impairment, physical, medical rating of 181 182
Incision for anterior capsulotomy for adduction deformity of fore part of foot, 101 102
  closure of release operation for clubfoot 99
  for insertion of hip prostheses, choice of, 307
  low posterior in femoral neck frac t res, 311 316
  for operation on menisci of knee, 158-159
  in release operation for lubfoot 96
  skin, in tendon transfer in repair of clawhand, 83, 84
Index finger extensor hood of 67
  tendon and nerve, 61
Industrial low back cripple diagnosis, treatment, and rehabilitation of, 173-182
Inequalities in growth, conditions with, 220
Infants, acute hematogenous osteomyelitis in, therapy 239
Infection following self-locking hip prosthesis operations, 318
  operative, after insertion of femoral head prosthesis, 296
Injuries, ankle 35-44
  to athletes, losing comments, 49
    opening remarks, 13
    prevention of 17 18
    principles of treatment, 15 16
  bone of knee 32 34
  to elbow complications with, 275
  knee 29 34
  of menisci of knee, 157 158
Ink writers for muscle studies, 248
Internal derangements of knee 161 169
  fixation of femoral neck fractures, historical background, 278
    of hip erms metal femoral head 299-300
Interosseus muscles of hand anatomy 64 81
Interphalangeal and metacarpal joints, anatomy 68
Interspace narrowed, as indication for fusion after operation for removal of protruded intervertebral disc, 214
I tervertebral disc syndromes, 177 178
  disc, lumbar protruded, end results of removal of with and without fusion, 215-216
Intra-articular fractures about knee 32
Intracapsular fracture of hip fresh, use of prosthesis in, 287 291
Intractable low back pain, special management, 180
Intramedullary prosthesis for femoral neck fractures, 280 284 285
    for hip fractures, Moore s, 309
      shape nd size 302
Intrinsic muscles of hand, 63-66
Invasiveness of bacteria, definition 234
Inversion of heel in clubfoot, medial capsulotomies for 110 114 116
Involutional stage of nodule in Dupuytren s contracture, 71 74

J

Joint changes in Dupuytren s contracture, ?2, 73 75
Judet method of treatment of femoral neck fractures, 279
  prosthesis for hip fractures 309

K

Kirschner wires in treatment of congenital convex pes valgus, 126 142 145
Knee 153-169
  arthritis in, 164 166
  extension action potentials of vastus lateralis on, 257
  fractures, 32 34
  injuries 29-34
    in athletes, prevention of 28
    bone 32 34
    physical examination, 29
    soft tissue, 29-32
  internal derangements of 161 169
  joint, dissection of, 155
    function of menisci, 155
    incision nd anatomy of lateral approach 158
    instability of 158
  locking of, 161 166
  loose bodies in, 165-166
  menisci of comparativ anatomy 153-156
    cysts, 164
    injuries and affections, 153-159
    lesions, 161 164
    surgical approaches, 158-159
    tears, 16? 163
  muscle rehabilitation, 47
  taping 27

L

Last straw of stress," 174 176 177
Lateral forces in correction of scoliosis, 208 209
Leg length, Gill and Abbott s method of prediction, 223
  inequalities in, causes, 220
  motions involved in running, 17
Legal aspects of use of prostheses, 323
LeRoy Lowman operation, 73
Lesions of menisci 161 164
  osteomyelitic, development and extension of 234
    manifestations of 235
    pathogenesis of 233
    saucerization and primary closure under antibiotic control, 243-245

Femur medial condyle of osteochondritis dissecans of, 164-165
  patella and, chondromalacia of, 166-169
F nestrations in stem of intramedullary hip prostheses, 306
Fibrillary potential as diagnostic sign, 247
Fibrosis, periarticular after elbow injuries 275
Fibrous tissue structures resisting correction of congenital clubfoot and metatarsus varus, surgical release of 100-116
Fibula, adduction-external rotation fracture, 43
Fibular key to analysis of ankle injuries 41
Filter aluminum, for bone density measurement, 285
Fingers, anatomy 80-82
  clawed, surgical repair of, 85-88
  extensor hood of 66-68
  and hand, taping 26
  metacarpal nd interphalangeal joints, 68
  muscles, anatomy 82
    rehabilitation, 47
  nodules of Dupuytren s contracture, 72 73
  surface anatomy 53
  tendons, 60-62
Fixation, internal, of femoral neck fractures, historical background, 278
    of hip, errus metal femoral head, 299-300
Flatfoot, congenital convex pes valgus differentiated from, 117
Flexibility of athlete, examination of, 19
Flexor tendons of fingers, 6
Foot 91 150
  fore part of anterior capsulotomies for adduction deformity of 101 110 111 113
  hind part of, medial capsulotomies for deformity in clubfoot, 110 114-116
  motions involved in running, 17
  muscles, diagrams, 251 252 .53
    rehabilitation, 48
  nodules of Dupuytren s contracture 74
  operati technique of subtalar f sion 129-131
    algus deformities of, subtalar f sion in treatment, 1 7 150
Forces used in correcting scoliosis, 193-194
Fowler extensor transplant in repair of clawed fingers, 85 86 87
  tenodesis in repair of clawed fingers, 87
Fracture-dislocations of elbow 274
Fractures, 263-323
  ankle, 137 142
  avascular necrotic femoral head, prosthesis for 320
  capitellum, 271
  coronoid process 267 270
  elbow in adults, operative treatment, 265-276
    complications, 275
    open, 275
  femoral neck (*se also* Femoral neck fractures)
      fresh, Moore self-locking V talli m prosthesis in, 309-320
        treatment with prosthesis, symposium on, 278-323
      primary prosthetic replacement in 283-286
  hip (*see also* Femoral neck fractures)
    delay in treatment indication for prosthesis, 294
    "falling part" after reduction and nailing prosthetic replacement, 294
    fresh, choice of prosthesis 301 307
      indications for prosthesis, 299-300
      treatment with prosthesis 292 298
    intracapsular fresh, use of prosthesis in, 287 291
    poor reduction of, indication for prosthesis, 293
  humerus, 270- 75
    lateral and medial epicondyles, 271
  knee, 32 34
  olecranon, 270
  patella, osteochondral, 168 169
  Pauwel's type 3 prosthesis indicated for 294
  radius head, 266-267
  of spine 174-176
    differential diagnosis of, 175
    treatment, 175-176
  T into elbow joint, 272
  transcondylar 273
  trochlea, 272
  ulna 268-270
Fresh fracture, definition, 292
  femoral neck fractures, Moore self locking Vitallium prosthesis in, 309-320
      treatment with prosthesis, symposium on, 278-323 (*see also* Femoral neck fractures)
  hip fractures, choice of prosthesis, 301 307
      indications for prosthesis, 299 300
      intracapsular use of prosthesis in, 287 291
      treatment with prosthesis, 292 298
Fulminating cases of acute hematogenous osteomyelitis, 235 239
Functional anatomy of hand, 80
Fusion areas in scoliosis, 190 192, 193
    types of curves, 194
  of curves of spine errors in, 195
  spinal, in correction of paralytic scoliosis, 198 200, 201
    end results of removal of protruded lumbar intervertebral discs with and without, 213-216
    indications for with operation for removal of protruded intervertebral disc, 213-214
    operation to relieve low back pain, 179
  subtalar in treatment of valgus deformities of feet, 127 150

G

Gibson approach, insertion of femoral head prosthesis through, 295
    posterolateral, in hip fractures, low posterior approach compared with, 314-316
Gill and Abbott's method of growth prediction, 223
Goat and man, measuring percentages of growth in, 221
Goff's calculations of growth, 228, 229
Grafts, bone, i tarsal sinus, insertion of 130
Grice procedure of stabilization of reduction of congenital convex pes algus, 126
Growth adaptivity asymmetry and, of man, 219
  of chimpanzee and man compared 219
  curves, Bayley s, 222
  increments of lower extremity expected, methods of calculating 221-230
  inequalities in, conditions with, 220
  prediction, Gill and Abbott method, 223
  of unequal extremities measuring and predicti g, 219-230

H

Hamstrings, electromyographic study of, 254 260
  taping 27
Hand, 53-90
  anatomy 53-69
  Dupuytren s contracture 70-78
  functional anatomy 80
  intrinsic muscles, 63-66
  palm of anatomy 57-63
  paralytic, surgery of 79-89
  plates for measuri g bone ages, 228
  skin of, 53

Hand—Cont d
structural anatomy 80-82
surface anatomy 53
taping 26
tendons of 54 55
venous drainage 53
Hark operation for congenital convex pes valgus, 142
Head of radius, fractures of, 266-267
Healing of surgically treated osteomyelitic lesions, problems of 242 43
Hemarthrosis in knee injury 29
Hematogenous osteomyelitis, acute 232 39
postacute 240-241
Hematoma in Charley horse 46
Hip, flexion contractures in athletes, causes of 19
fractures (see also Femoral neck fractures)
fresh, choice of prosthesis in, 301 307
indications for prosthesis, 299-300
intracapsular use of prosthesis in, 287 291
treated with prosthesis, 292 298
indications for prosthesis, 292 294
nailing of, arguments for and against, 299-300
primary prosthetic replacement in, 283-286
treatment with prostheses, complications of 281 282 284 286
motions involved in running, 17
muscle rehabilitation, 47
pain after use of prosthesis, cause of, 307 308
prosthesis in treatment of femoral neck fractures, historical background, 279
traumatic dislocation of with fracture of femoral head, 320
Historical background of treatment of fresh fractures of femoral neck, 278-279
Humerus, fractures of 270-273
Hydrocortisone in treatment of myositis ossificans 275
Hyperemia, cause of complication in use of prosthesis in hip fracture, 291
Hypothenar eminence anatomy 82
muscles of hand, 65 66

I

Idiopathic scoliosis, 202, 203 204
Iliopsoas muscle electromyography in study of, 254 256
Iliotibial band in causation of scoliosis rol of 197 201
Impairment, physical, medical rating of 181 182
Incision for anterior capsulotomy for adduction deformity of fore part of foot, 101 102
closure of release operation for clubfoot, 99
for insertion of hip prostheses, choice of 307
low posterior in femoral neck fractures, 311 316
for operation on menisci of knee, 158-159
in release operation for clubfoot 96
skin, f tendon transfer in repair of clawhand, 83, 84
Index finger extensor hood of 67
tendon and nerve, 61
Industrial low back cripple diagnosis treatment, and rehabilitation of, 173-182
Inequalities in growth, conditions with, 220
Infants, acut hematogenous osteomyelitis in, therapy 239
Infection following self-locking hip prosthesis operations, 318
operative after insertion of femoral head prosthesis, 296
Injuries, ankle 35-44
to athletes closing comments, 49
opening remarks, 13
prevention of 17 28
principles of treatment, 15 16
bone of knee 32 34
to lbow compl cations with, 275
knee, 29-34
of menisci of knee 157 158
Ink writers for muscle studies 248
I ternal derangements of knee 161 169
fixation of femoral neck fractures, historical background, 278
of hip ersus metal femoral head, 299-300
I terosseus muscles of hand, anatomy 64 81
Interphalangeal and metacarpal joints, anatomy 68
Interspace narrowed, as indication for fusion after operation for removal of protruded intervertebral disc, 214
Intervertebral disc syndromes 177 178
disc lumbar protruded, end results of removal of, with and without fusion, 213-216
Intra-articular fractures about knee 3?
Intracapsular fracture of hip, fresh use of prosthesis in, 287 291
Intractable low back pain, special management, 180
Intramedullary prosthesis for femoral neck fractures, 280 284 85
for hip fractures, Moore s, 309
shape and size 302
Intrinsic muscles of hand, 63-66
Invasiveness of bacteria, definition 234
Inversion of heel in clubfoot medial capsulotomies for 110 114 116
Involutional stage of nodule in Dupuytren s contracture, 71 74

J

Joint changes in Dupuytren s contracture 72, 73 75
Judet method of treatment of femoral neck fractures, 279
prosthesis for hip fractures, 309

K

Kirschner wires in treatment of congenital convex pes valgus, 126 142, 145
Knee 153-169
arthritis in, 164 166
extension, action potentials of vastus lateralis on, 257
fractures, 32 34
injuries, 29-34
in athletes, prevention of, 28
bone, 32 34
physical examination, 29
soft tissue, 29-32
internal derangements of 161 169
joint, dissection of, 155
function of menisci, 155
incision and anatomy of lateral approach 158
instability of 158
locking of, 161 166
loose bodies in, 165-166
menisci of, comparative anatomy 153-156
cysts, 164
injuries and afflictions, 153-159
lesions, 161 164
surgical pproaches, 158-159
tears, 162 163
muscle rehabilitation, 47
taping 27

L

"Last straw of stress," 174 176, 177
Lateral forces in correction of scoliosis, 208 209
Leg length, Gill and Abbott s method of prediction, 223
inequalities in, causes, 220
motions involved in running, 17
Legal aspects of use of prostheses, 323
LeRoy Lowman operation, 73
Lesions of menisci, 161 164
osteomyelitic, development and extension of, 234
manifestations of 235
pathogenesis of, 233
saucerization and primary closure under antibiotic control, 43-245

Lesions of menisci—Cont d
surgical, 236
problems of repair of 242 243
Ligaments of knee anatomy 156
injuries to 30
and tendon sheaths, release operation for clubfoot, 99
Light bulb prosthesis for femoral neck fractures, 279 284 285
Limp in patients wearing hip prosthesis, 319
Local therapy of osteomyelitic lesions, 238-239
Locked" knee joint, treatment of, 32
Locking of knee 161 166
Locomotion, electromyography in study of, 251 261
Loose bodies in knee 165-166
Low back cripple industrial, diagnosis, treatment, and rehabilitation of, 173-182
pain of discogenic origin surgery for 178-179
intractable, special management, 180
after two or more spinal operations, 178
relief of, after removal of protruded intervertebral disc with and without fusion, 15 216
routine management, 180
posterior approach in hip fractures compared with posterolateral (Gibson) approach, 314-316
Lumbar intervertebral discs, protruded, end results of removal of with and without fusion, 213-216
vertebrae spondylolysis and spondylolisthesis, 177
Lumbrical muscles of hand, anatomy 64 65 82

M

Main en griffe (clawhand) 79
Materials for hip prostheses, comparison of 318
for prosthesis for intracapsular hip fractures, 289
Mayo Clinic experience with femoral head prostheses, 292 298
operations for protruded intervertebral disc 214
Measurement of bone density 285 286
of stature method of, 227
Measuring and predicting growth of unequal extremities 219-230
Mechanical axis of lower extremity study of, 253 254
Medial capsulotomies for correction of heel in clubfoot, 110 114-116
malleolar key to analysis of ankle injuries, 41
release operation, clubfoot, 96
Median nerve of hand, 58 60
and ulnar nerve paralysis cause of clawhand, 79 80
Medical rating of physical impairment, 181 182
Medicolegal implications of use of prostheses, 323
Menisci of knee comparative anatomy 153-156
cysts, 164
function, 155
injuries and affections 153-159
lesions, 161 164
surgical approaches, 158-159
tears, 162 163
Meniscus, medial, torn, repair of, 31
Mental confusion, postoperative complication of insertion of femoral head prosthesis, 296
patients, femoral neck fractures in, prosthesis for 320
Metacarpal and interphalangeal joints anatomy 68
Metal failure of hip prostheses 289
used in prosthesis for fresh hip fractures, 301
Metaphysis, osteomyelitic lesion in, 235
Metastatic malignancy patients, self-locking hip prosthesis for 319
Metatarsus varus and congenital clubfoot, anterior capsulotomies for 101 110, 111 115
surgical release of fibrous tissue structures resisting correction of 100-116
Microorganisms producing osteomyelitis, 234
Milwaukee brace for scoliosis, 210 211
Monteggia's fracture, 268, 269
Moore adjustable nails in hip fractures, 316
prosthesis for hip fractures, 293, 303 304
self-locking Vitallium prosthesis in fresh femoral neck fractures 309-320
Mortality rate in use of prosthesis for femoral neck fractures, 322
Motor unit, description of 246
Muscle exercise three-cycle count, 46
function, normal, electromyography in study of 257
imbalance, correction by tendon transplantation with subtalar fusion, 132
injuries with elbow fractures, 275
innervation and denervation, electromyography in study of 256
power after poliomyelitis, growth prediction by 224 226
rehabilitation, 46-48
training for sports, 21
Muscles of hand, anatomy
intrinsic, 63-66
of lower extremity actio
261
and tendons, release op
clubfoot, 98
Muscular behavior in l
electromyograph
of 251 261
study of, 246
types of electrodes, 24
of recording equipm
249
Musculoskeletal developmen
letes, examinati
19
Myopathies and atrophies
origin, different
electromyograph
257
Myopathy primary dis
from secondary
tromyography
Myositis ossificans as compl
elbow injuries,

N

Nailing of fractured hip,
for and against
Nails for internal fixation c
neck fractures,
background, 27
Moore adjustable, in hip
316
Narrowed interspace as indi
fusion after ope
removal of prot
tervertebral disc
Neck and back, exercises f
rehabilitation, 4
femoral fresh fractures
ment with
symposium on,
(see also Femo
fractures)
Nerve complications of ell
tures, 275
radial, paralysis of 88-89
Nerves of palm of hand, 58-
of wrist, 55-57
Neurodiagnosis, lectromyogr
250-251
Neurofibromatosis, scoliosis
206, 208
Newborn infant cause of cl
100
Newington method of
growth predictio
of taking orthoroentge
227
stature graph, 224
Nodules in Dupuytren con
stages, 71 74
therapy 75

O

Ober operation on heel in
110

Olecranon fractures of 270
Open fractures of lbow joint, 273
Operation on fract red lbow jol ts, 266-267
for primary prosthetic replacement in femoral neck fractures, technique nd postoper atrve care 284
for protruded intervertebral disc t M yo Clinic 214
release for clubfoot, 95-99
for removal of protruded inter ertebral discs, end results of 213-216
Operati reduction of congenital convex pes alqus, 123-126
tech ique of southern exposure approach in femoral neck fractures, 312 313 314 316
treatment of fra tures of elbow in adults, 265-276
Orthopaedic rehabilitation, 45
surgery applications of electromy ography in, 250-261
Orthopaedists, role in prevention of injuries to athletes, 14 15
Orthoroentgenograms, Newington method, 227
Oscillogram from normal gastroc nemius during walking 258
ariation of frequency recording range on, 250
Oscillographs for muscle studies, 248
Oscilloscope 248-249
sensitivity 257 258
Osmond-Clarke operation for congenital convex pes valgus, 14
Osteochondral fracture of knee joi t, 32, 33
of patella, 168, 169
Osteochondritis dissecans, 164 165
Osteochondromatosis, 165-166
Osteomyelitic lesions, saucerization and primary closure under antibiotic control, 243 245
surgically treated, problems of repair of 4 243
Osteomyelitis, 232 245
acute hematogenous 232 239
anatomical onsiderations, 232
bacteriological considerations, 234
chemical therapy 236
circulatory considerations, 233
classification 235
clinical observations, 234 235
differentiated from acut ar thritis, 235
fulminating 235 239
n nfants, therapy 239
invasi lements, 235
local therapy 238-239
pathogenesis of hypotheses, 233
Ost omyeliti acute hematogenous—Cont d
pathomechanics, 234
physiological considerations, 233
primary focus therapy 239
res lts of therapy 239
serological therapy 236
surgical intervention 238
systemic therapy 235 238
therapy 235-239
toxigenic factors 235
chronic 241 245
conservati therapy 241-24
surg cal therapy 242 243
postacute hematogenous, 240-241
Osteoporosi as complication of primary prosthetic replacement in hip fractures, 285 286
nailing of hip fractures in, 300
senescent, of spine 174

P

Paget disease nailing of hip fracture in, 300
Pain in hip caused by weight bearing and loose prosthesis, 319
after use of prosthesis, cause of 307 308
low back of discogenic origin, surgery for 178-179
industrial, 173-182
intractable, special management, 180
rel ef of after removal of protruded tervertebral disc with and without fusion, 215 216
routine management, 180
Palm of hand, anatomy 57-63
blood supply 57
nerves, 58-60
nodules of Dupuytren s contra ture 71 72
subcutaneous fasciotomy on, 75-78
Palmar aponeurosis, anatomy 57
spaces of hand, 62
surface of hand, 53
Paraly is median and ulna nerv cause of clawhand, 79 80
radial nerve 88-89
Paralytic hand, surgery of 79-89
scoliosis, management of 196-201
valgus deformities subtalar fusion of 129
Parent extremity length as base line for determination of child expected growth 221
Parkinson disease nailing of hip *fractures in* 300
self locking hip prosthesis for patients, 319
P tella nd femur chondromalacia of 166-169
osteochondral fracture of 168 169
Pathogenesis of acute hematogenous osteomyelitis hypotheses of 233
Patholog cal fracture of femoral head, treatment with prosthesis 293
Pathomechanics of acute hematogenous osteomyel tis, 234
of stabilization of subtalar joint, 127 128
Pauwel type 3 *fracture in aged,* self locking hip prosthesis indicated for 319
prosthesis indicated for 294
Pectoral muscles, shortening of in athletes, 19
P l ic tilt, 190 191 192
in scoliosis, iliotibial band in causation of 197 201
Penicillin treatment of acute hema togenous osteomyelitis, 236
Periarticular fibrosis following elbow *fracture,* 275
Permanent disability evaluation of 181
Peroneal palsy postoperative compli cation of insertion of femoral head prosthesis, 296
Peroneals, relation to subtalar axis, 252
transfer to dorsum of foot and position of subtalar axis, 253
Pes valgus congenital convex, diag *nosis,* 117 120
subtalar fusion in treatment of 139-145
treatment, 121 126
Physical examination, importance to thletic safety 18
in knee injuries, 29
impairment, medical rating of 181 182
Physician role in evaluation of permanent impairment, 181
Physiological considerations, acute hematogenous osteomy elitis, 233
Plantar flexed talus, treatment, 139-145
Plaster jacket, distraction, for scoliosis, 210
splints for sprains 44
Playing surf ce in prevention of athletic injuries, 21
Pneumonia, postoperati complication of insertion of femoral head prosthesis, 296
Poliomyelitis as cause of inequality of leg length, 221
correction of valgus deformity fol lowing 133 135
lectromyography in diagnosis of 250
epiphyseal disc growth percentages in, 229

Lesions of menisci—Cont'd
surgical, 236
problems of repair of 242 243
Ligaments of knee, anatomy 156
injuries to, 30
and tendon sheaths, release operation for clubfoot, 99
Light bulb prosthesis for femoral neck fractures, 279 284 285
Limp in patients wearing hip prosthesis, 319
Local therapy of osteomyelitic lesions, 238-239
"Locked" knee joint, treatment of 32
Locking of knee 161 166
Locomotion, electromyography in study of 251 261
Loose bodies in knee 165-166
Low back cripple, industrial, diagnosis, treatment, and rehabilitation of, 173-182
pain of discogenic origin, surgery for 178-179
intractable special management, 180
after two or more spinal operations, 178
relief of, after removal of protruded intervertebral disc with and without fusion, 215 216
routine management, 180
posterior approach in hip fractures compared with posterolateral (Gibson) approach, 314 316
Lumbar intervertebral discs, protruded, end results of removal of with and without fusion, 213-216
vertebrae, spondylolysis and spondylolisthesis, 177
Lumbrical muscles of hand, anatomy 64, 65 82

M

Main en griffe (clawhand) 79
Materials for hip prostheses, comparison of, 318
for prosthesis for intracapsular hip fractures, 289
Mayo Clinic experience with femoral head prostheses, 292 298
operations for protruded intervertebral disc 214
Measurement of bone density 285 286
of stature, method of, 227
Measuring and predicting growth of unequal extremities 219-230
Mechanical axis of lower extremity study of, 253 254
Medial capsulotomies for correction of heel in clubfoot 110 114 116
malleolar key to analysis of ankle injuries, 41
release operation, clubfoot, 96
Median nerve of hand, 58 60
and ulnar nerve paralysis, cause of clawhand, 79 80
Medical rating of physical impairment, 181 182
Medicolegal implications of use of prostheses, 323
Menisci of knee comparative anatomy 155-156
cysts, 164
function, 155
injuries and affections, 155-159
lesions, 161 164
surgical approaches, 158-159
tears, 162 163
Meniscus, medial, torn, repair of 31
Mental confusion, postoperative complication of insertion of femoral head prosthesis, 296
patients, femoral neck fractures in, prosthesis for 320
Metacarpal and interphalangeal joints anatomy 68
Metal failure of hip prostheses, 289
used in prosthesis for fresh hip fractures, 301
Metaphysis, osteomyelitic lesion in, 233
Metastatic malignancy patients, self locking hip prosthesis for 319
Metatarsus arts and congenital clubfoot, anterior capsulotomies for 101 110 111 115
surgical release of fibrous tissue structures resisting correction of 100-116
Microorganisms producing osteomyelitis, 234
Milwaukee brace for scoliosis, 210 211
Monteggia's fracture 268 269
Moore adjustable nails in hip fractures, 316
prosthesis for hip fractures, 293 303 304
self-locking Vitallium prosthesis in fresh femoral neck fractures 309-320
Mortality rate in use of prostheses for femoral neck fractures 3??
Motor unit, description of, 246
Muscle exercise three-cycle count, 46
function, normal, electromyography in study of 257
imbalance, correction by tendon transplantation with subtalar fusion, 132
injuries with elbow fractures 275
innervation and denervation, electromyography in study of. 256
power after poliomyelitis growth prediction by 224 226
rehabilitation. 46-48
training for sports, 21
Muscles of hand, anatomy 80-82
intrinsic, 63-66
of lower extremity action of, 251 261
and tendons, release operation for clubfoot, 98
Muscular behavior in locomotion, electromyography in study of, 251 261
study of 246
types of electrodes, 247 248
of recording equipment, 248-249
Musculoskeletal development of athletes, examination of, 18 19
Myopathies and atrophies of central origin, differentiation by electromyography 256-257
Myopathy primary distinguished from secondary by electromyography 250
Myositis ossificans as complication of elbow injuries, 275

N

Nailing of fractured hip, arguments for and against, 299-300
Nails for internal fixation of femoral neck fractures, historical background, 278
Moore adjustable in hip fractures, 316
Narrowed interspace as indication for fusion after operation for removal of protruded intervertebral disc, 214
Neck and back, exercises for muscle rehabilitation, 47
femoral, fresh fractures of, treatment with prosthesis, symposium on, 278-323 (see also Femoral neck fractures)
Nerve complications of elbow fractures, 275
radial, paralysis of, 88-89
Nerves of palm of hand, 58-60
of wrist, 55-57
Neurodiagnosis electromyography for 250-251
Neurofibromatosis, scoliosis due to, 206, 208
Newborn infant, cause of clubfoot in, 100
Newington method of extremity growth prediction, 230
of taking orthoroentgenograms, 227
stature graph, 224
Nodules in Dupuytren's contracture stages, 71 74
therapy 75

O

Ober operation on heel in clubfoot, 110

Olecranon, fractures of 270
Open fract res of elbow joi t, 273
Operation on fractured elbow joints, 266-267
for primary prosthet c replacement in femoral neck fract res technique and postoperative care 284
for protruded intervertebral disc t Mayo Clinic 214
release for clubfoot, 95-99
for removal of protruded i tervertebral discs end results of, 213-216
Operativ reduction of congenital convex pes algus, 123-126
technique of southern exposure approach in femoral neck fractures, 312 313 314-316
treatment of fractures of elbow in dults, 65-276
Orthopaedic rehabilitation, 45
surgery pplications of lectromyography in, 250-261
Orthopaedists, role in prevention of injuries to thletes, 14 15
Orthoroentgenograms, Newington method, 227
Oscillogram from normal gastrocnemius during walking, 258
ariation of frequency recording range on, 250
Oscillographs for muscle studies, 248
Oscilloscope, 248-249
sensitivity 257 258
Osmond-Clarke operation for congenital convex pes valgus 142
Osteochondral fracture of knee joint, 32 33
of patella, 168, 169
Osteochondritis dissecans 164-165
Osteochondromatosis, 165-166
Osteomyelitl lesions, saucerization and primary closure nder antibioti control 243-245
surgically treated, problems of repair of 242 243
Osteomyelitis, 232 245
acute hematogenous 232 239
anatomical considerations, 232
bacteriological considerations, 234
chemical therapy 236
circulatory considerations, 233
lassification 235
clinical obser tions, 234-235
differentiated from acute thritis, 235
f lminating 235 239
in infants, therapy 239
invasiv elements, 235
local therapy 238-239
pathogenesis of hypotheses, 233
Osteomy litis, acute hematogenous—Cont d
pathomechanics, 234
physiologic l considerations 233
primary focus, therapy 239
results of therapy 239
serological therapy 236
surgical intervention 238
systemic therapy 235 238
therapy 235-239
toxigenic factors 235
chronic 241 245
conservative therapy 41 242
surgical therapy 242 243
postacut hematogenous, 240-241
Osteoporosis as complication of pri mary prostheti replacement in hip fractures, 285 286
nailing of hip fractures in, 300
senescent, of pine 174

P

Paget s disease naili g of hip fracture in, 300
Pain in hip caused by weight bearing and loose prosthesis, 319
after use of prosthesis cause of 307 308
low back of discogenic origin, *surgery for 178-179*
industrial, 173 182
intractable special management, 180
relief of after removal of protruded intervertebral disc with and without fusion, 215 216
routin management, 180
Palm of hand, anatomy 57-63
blood supply 57
nerves, 58-60
nodules of Dupuytren contracture 71 72
subcutaneous fasciotomy on, 75-78
Palmar aponeurosis anatomy 57
spaces of hand, 62
surface of hand, 53
Paralysis, median and ulnar nerve, cause of clawhand, 79 80
radial nerve 88-89
Paralyti hand, surgery of 79-89
scoliosis management of 196-201
algus deformities, subtala fusion of 129
P rent extremity length as base line for determination of child' expected growth 221
Parkinson s disease nailing of hip fractures in 300
self-locking h p prosthesis fo patients, 319
P tella nd femu chondromalacia of 166-169
osteochondral fra ture of, 168 169
Pathogenesis of acute hematogenous osteomyelitis hypotheses of 233
Pathological fracture of femoral head, treatment with prosthesis 293
Pathomechanics of acute hematogenous osteomyelitis 234
of stabilization of subtalar joint, 127 128
Pauwel type 3 fracture n aged self-locking hip prosthesis indicated for 319
prosthesis indicated for 294
Pectoral muscles, shortening of in athletes, 19
Pelvic tilt, 190 191 192
in scoliosis, iliotibial band n causation of 197 201
Penicillin treatment of acute hematogenous osteomyelitis 236
Periarticular fibrosis following elbow fracture, 275
Permanent disability evaluation of 181
Peroneal palsy postoperative complication of insertion of femoral head prosthesis, 296
Peroneals relation to subtalar axis, 252
transfer to dorsum of foot and position of subtalar axis 253
Pes valgus congenital convex, diagnosis, 117 120
subtalar fusion in treatment of 139-145
treatment, 121 126
Physical examination, importance to athletic safety 18
in knee injuries, 29
impairment, medical rating of 181 182
Physician role in evaluation of permanent impairment, 181
Physiological considerations, acute hematogenous osteomyelitis 233
Plantar-flexed talus, treatment, 139-145
Plaster jacket, distraction, for scoliosis 210
splints for sprains, 44
Playing surface in prevention of athletic injuries, 21
Pneumonia, postoperative complication of insertion of femoral head prosthesis, 296
Poliomyelitis as cause of inequality of leg length 221
correction of valgus deformity following, 133 135
electromyography in diagnosis of, 250
epiphyseal disc growth percentages in, 229

Poliomyelitis—Cont'd
fusion area, 194
muscle power following growth prediction by 224-226
scoliosis due to 198, 199-201
Postacute hematogenous osteomyelitis, 240-241
Postoperative care after southern exposure approach in femoral neck fractures, 316
after spinal fusion, 179
complications of prosthetic replacement treatment of femoral neck fractures, 296
management of patient with femoral head prosthesis, 294
Postural conditions causing low back pain, 173
Posture of athlete, examination of, 19
Preoperative management of patient with femoral neck fracture, 294
Prevention of athletic injuries, 17-28
Primary prosthetic replacement in fractures of femoral neck, 283-286
Private practice, treatment of hip fractures survey 281
Problem feet 93-95
Procaine contraindicated for athletic injuries 44
Proliferative stage of nodule in Dupuytren's contracture, 71
Prostheses, comparison of materials of, 318
for femoral neck fractures, indications for 288
materials of, 289
primary replacement by 283-286
summary of discussion, 322-323
symposium on, 278-323
for hip fractures choice of 301-307
complications caused by 281-282 284-286, 289-291
incision for insertion of, 307
indications for 299-300
statistical review of 280-282
medicolegal implications of use of 323
Prosthesis, dislocation of, following operation on hip fractures, 278 284-286, 289
femoral head, indications for 292-294
postoperative management of patient with, 294
surgical technique of insertion, 295
types of fractures suitable for statistical review 297
hip, fresh fractures treated with, 292-298
for intracapsular fracture, 287-291
pain caused by 307-308
self-locking, indications for 319-320
Prosthesis—Cont'd
in treatment of femoral neck fractures, historical background, 279
improper seating of cause of complication in hip fracture, 290-291
insecure in femur cause of pain in hip 290, 291
Moore self-locking Vitallium, in fresh femoral neck fractures, 309-320
wearing of in hip fractures, bone density studies in relation to, 286
Prosthetic replacement, primary in fractures of femoral neck, advantages and disadvantages, 283
Protective equipment, athletic, 21
Protruded lumbar intervertebral discs, end results of removal of with and without fusion, 213-216
Protrusion, disc, 178

Q

Quadriceps muscle phasic activity of oscilloscope study 259

R

Rabbits, measurement of growth increment in, 220
Radial nerve 60
paralysis 88-89
Radiation, excessive, dead heads from, indication for femoral head prosthesis in hip fracture 300
Radiographic density of bone, measurement of 286
Radius, head of fractures of 266-267
Recording equipment for action potential, 248-249
Reduction of ankle fractures, 38
poor of fracture indication for prosthesis, 293
Rehabilitation in athletes, 45-46
diagnosis, and treatment of industrial low back cripple, 173-182
muscle, 46-48
Release operation for clubfoot, 95-99
indications and contraindications, 96
postoperative care 99
technique 96-99
surgical, of fibrous tissue structures resisting correction of congenital clubfoot and metatarsus arcs 100-116
Remedial exercises for back, 46-47
Residual stage of nodules of Dupuytren's contracture 74
Rheumatoid arthritis patients, self locking hip prosthesis for 320
Riordan tenodesis in repair of clawed fingers, 86-87
Rocker foot, 139 (see also Congenital convex pes valgus)
Roentgenograms of congenital convex pes valgus 118-125
of curves of spine, 187-188, 189
of fusion of curves in spine 194-195
of knee injuries, 30-31
of pelvic tilt in scoliosis 198-199
Roentgenographic and pathological changes in postacute hematogenous osteomyelitis, 40
Rotation injury knee, 31
of vertebrae, 186, 189
forced, 194
Rotational lag 189
Running, motions involved in, 17
Rupture of muscle in "Charley horse," 46

S

Sacrospinalis and abdominal muscles in paralytic scoliosis, role of, 196
Salvage use of hip prosthesis, 303, 305
incision for 307
Saucerization and primary closure under antibiotic control of osteomyelitic lesions, 243-245
Scholarship, athletic, 14
Sciatica, relief of after removal of protruded intervertebral disc with and without fusion, 213-216
Scoliosis, abdominal fascial transplants in treatment of 197
associated with arachnodactyly 207-208
congenital, 203-205
conservative treatment of, 195
distraction plaster jacket for 210
forces in correction of, 193-194
analysis of, 208-210
fundamental principles and treatment, 184-211
fusion areas 190-192, 193
idiopathic, 202, 203-204
iliotibial band in causation of, 197-201
due to neurofibromatosis, 206, 208
paralytic, abdominal and sacrospinalis muscles in, 196
management of, 196-201
with pelvic tilt, 190-191-192
types of 203-208
Scoliotic curve, 189-190 193
Self-locking Vitallium prosthesis, Moore's, in fresh femoral neck fractures, 309-320
Senescent osteoporosis of spine 174
Serological therapy of osteomyelitic infections, 236

Shape of prosthesis for fresh hip fractures, 301 307
Skin, taping 27
Shock in self-locking hip prosthesis operations, 318
  therapy self-locking hip prosthesis for patients undergoing 320
Shortening of lower extremities after poliomyelitis, prediction of 224 226
Shoulder dislocation in sports, causes of 19
  muscle rehabilitation, 47
  taping, 25
Skeletal system, examination in athletes, 20
Skin of hand, 55
  incisions in tendon transfer in repair of clawhand, 83 84
Soft tissue disorders causing inequalities in leg lengths, 220
  injuries, knee 29-32
South Carolina State Hospital patients with femoral neck fractures, results of operation in, 316-317
Southern exposure approach in femoral neck fractures, 311 316
Spasm in "Charley horse" 46
  in poliomyelitis, detection by electromyography 250, 251
Spinal column values 181
  cord lesions electromyography in detection of level of, 251
  disabilities in athletes, causes of 19
  injuries in football players, 20
  operations, two or more intractable low back pain after 178
Spine 173-216
  analysis of curves, 184 196
  chronic arthritis, 176
  curves in, deformities produced by location and length of 196
  fractured, differential diagnosis, 175
    treatment, 175-176
  fractures of 174 176
  fusion of end results of removal of protruded lumbar intervertebral discs with and without, 213-216
  senescent osteoporosis of 174
Splint, Denis Browne (kicking) 94
Spondylolisthesis lumbosacral 176-177
Spondylolysis lumbosacral 176-177
Sports, ankle injuries in, 35-44
  injuries, prevention of, 17 18
  knee injuries in, 29-34
Sprains, ankle grades of 40
  treatment, 39
  taping of 25-27
Spreading factor of bacteria, 234
Stabilization of subtalar joint, pathomechanics of, 127 128
Stainless steel prosthesis for femoral head and neck 287 289
Staphylococcal infections, broad-spectrum antibiotics for 237
Staphylococcus producing osteomyelitis 234
Statistical review of use of prostheses in fresh fractures of femoral neck 280-282
  summary of results in Mayo Clinic series of prosthetic replacements in femoral neck fractures, 297
Stature graphs, Bayley 222
    Newington 224
  measurement method of 227
Steel prosthesis in fresh hip fractures, contraindications, 301
Stem prostheses for hip fractures, 302 303 304 305 306
    disadvantages of 309 310
Stockinette suspension for fractures of ankle 42 43
Strains postural, causes of 173
Streptococcus producing osteomyelitis 234
Streptomycin treatment of acute hematogenous osteomyelitis, 237
Structural anatomy of hand, 80-82
Subcutaneous dissection, clubfoot operation, 96
  fasciotomy in Dupuytren's contracture 75-78
Sublimis tendon transplant, Bunnell's, in repair of clawed fingers, 85
Subtalar fusion, age of patient at operation, 132
    for congenital convex pes valgus, 139
      talocalcaneal condition, 145 148-150
    late changes in adjacent articulations, 137 139
    operative technique 129-131
    reported experience with, 129
    results and late complications, 132 137
    tendon transplantation with, 132
    for valgus deformities, 127 150
      caused by cerebral palsy 145
  joint axis, electromyography in study of 251 252 253
    stabilization of, pathomechanics 127 128
Sulfa drugs in blood stream infections efficacy of, 236
Summary of discussion on prostheses for fresh femoral neck fractures, 322 323
Supracondylar fracture of humerus, oblique, 272
Surgery for low back pain of discogenic origin, 178-179
Surgery—Cont d
  of paralytic hand, 79-89
  for spondylolysis, 177
Surgical approaches to hip in intracapsular fractur 287
    to treatment of meniscI of knee 158-159
  care of unequal extremities, 219-230
  infections osteomyelitic, 236
  release of fibrous tissue structures resisting correction of congenital clubfoot and metatarsus varus, 100-116
  repair of clawhand, 82-88
  technique for insertion of femoral head prostheses, 295
  treatment of acute hematogenous osteomyelitis, time of intervention, 238
    of ankle fractures, 38
    of chronic osteomyelitis 242
    of comminuted fractures of head of radius, 266-267
    of Dupuytren's contracture 75-78
    of fractures of elbow in adults, 265-276
Sutures, release operation for clubfoot, 99
Symposium on injuries to athletes, 11-49
  on treatment of fresh fractures of femoral neck with prosthesis, 278-323
Synovitis, villonodular caused by steel hip prosthesis, 301 307
Systemic therapy of acute hematogenous osteomyelitis, 235 238

T

Talocalcaneal coalition, congenital, subtalar fusion for 145 148-150
Talonavicular joint changes following subtalar fusion, 138
Talus, plantar-flexed, 128
  treatment, 139-145
  position in valgus deformity 127 128
  vertical, diagnosis, 117 120
    treatment, 121 126
Taping, athletic, 21 25-27
Tarsal sinus, insertion of bone grafts in, 130
Team approach to analysis of child's growth, 221
Tears of meniscus of knee, 162 163
Tendon sheaths and ligaments, release operation for clubfoot, 99
  transplantation, Bunnell's multiple sublimis, in repair of clawed fingers, 85

Tendon transplantation—Cont'd
  Fowler's extensor in repair of clawed fingers, 85 86, 87
  new method, in repair of clawed fingers 88
  in repair of thumb in clawhand, 82-85
  with subtalar fusion in correction of valgus deformities, 132
Tendons to fingers 60-62
  and muscles, release operation for clubfoot, 98
  of wrist and hand, anatomy 54-55
Tenodesis, Fowler in repair of clawed fingers, 87
  Riordan, in repair of clawed fingers, 86 87
Terminal illness patients, self-locking hip prosthesis for 319
T-fractures into elbow joint, 272
Thenar eminence anatomy 80
  muscles of hand, 63
Thigh taping, 27
Thompson prosthesis for hip fractures, 303 304
Thumb, anatomy 80-82
  dorsal view 64
  surgical repair in clawhand, 82-85
  taping, 26
Tibial spine fractures, 34
Tibialis anticus, course of with respect to subtalar axis, 252
  paralysis dorsiflexion in 254
  posticus relation to subtalar axis, 252
Titanium for prostheses 318
Toe, taping, 26
Tonsil snare to divide attachment of meniscus, 162
Toxigenicity of bacteria, definition, 234
Transcondylar fractures, 273
Transplantation, tendon (see Tendon transplantation)
Transplants abdominal fascial, in treatment of scoliosis, 197
Traumatic dislocation of hip with fracture of femoral head, prosthesis for 320
Treatment, diagnosis and rehabilitation of industrial low back cripple, 173-182
  of fractured spine 173-176
  of fresh fractures of femoral neck with prosthesis symposium on, 278-323
  operative, of fractures of elbow in adults, 265-276
Trochlea, fractures of 272
Turnbuckle cast for scoliosis, 210

U

Ulna, fractures of, 268-270
Ulnar and median nerve paralysis, cause of clawhand, 79 80
  nerve anatomy 58-59
    injuries with fracture 275
Unequal extremities, surgical care of 219-250
"Unhappy triad, O'Donoghue's, 31 32
University of Illinois, results obtained with prostheses for fresh hip fractures, 281
Urinary tract infection, postoperative complication of insertion of femoral head prosthesis, 296

V

Valgus deformities caused by cerebral palsy subtalar fusion in 145
    paralytic reported experience with subtalar fusion 129
    following poliomyelitis, correction of 133, 135
    subtalar fusion in treatment of 127 150
Valgus deformities—Cont'd
    triple arthrodesis in correction of 132 134 136 137
  foot, paralytic, control of 128
Vascular injury with elbow fractures 275
Vastus lateralis, action potentials of, on knee extension, 257
  medialis, oscillogram of during extension of knee, 250
Veins of hand 53
Vertebrae lumbar spondylolysis and spondylolisthesis 177
  rotation of 186, 189
Vertebral bodies, differential diagnosis of fresh and ancient fractures and congenital or acquired defects of, 175
  fractures of 174 176
Vertical talus, diagnosis 117 120
  treatment, 121 126
Vitallium appliances, manufacture of 318
  prosthesis for fresh hip fractures, 301
    Moore self-locking in fresh femoral neck fractures, 309-320
Villinodular synovitis caused by steel hip prosthesis, 301 307
Volar carpal canal anatomy 57
  surface of wrist, anatomy 55-57

W

Walking electromyography in study of 251 261
Weight resistance in muscle rehabilitation, 46
Weight-training routine for athletes, 22 25
Wraps ankle 35 36
Wrist, dorsum of anatomy 54-55
  muscle rehabilitation, 47
  taping, 26
  volar surface anatomy 55-57

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